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RIBBON STRUCTURE IN GOLD–QUARTZ VEINS.

H. E. McKINSTRY AND E. L. OHLE, JR.

ABSTRACT.

The following conclusions result from field and laboratory studies of meso- and hypothermal vein matter in many widely separated districts: Quartz can replace country rock, whether directly or through the intermediary of carbonate, but in aluminous rocks such replacement does not normally extend far from the channelways in which solutions flow. Where there are closely spaced surfaces for attack by solutions, as in zones of shearing, sheeting, schistosity or thin bedding, replacement of rock by gangue ranges from partial to thorough. Partial replacement leaves residue of the layers or slices of wall rock interlaminated with the quartz, *i.e., book structure*. More advanced replacement obliterates original rock texture and leaves only films or septa representing (*a*) remnants of the book-leaves, (*b*) difficultly replaceable slips, and (*c*) material rejected by quartz while crystallizing. The result is *ribbon structure*. Replacement is comparatively ineffectual against walls of open fissures or large breccia fragments, where ratio of surface to volume is low. Quartz representing open space filling can exist in the same vein or vein system with laminated quartz; the contrasting structures, recording original differences in shape and mechanical origin of channelways, have structural significance.

INTRODUCTION.

MANY gold-bearing quartz veins of the mesothermal class, as well as some belonging to the hypothermal class, have a banded or streaked appearance occasioned by slabs or films of country rock or other material interlayered with the quartz (Fig. 1). When the bands are relatively thick—from a millimeter to several centimeters—and the material of which they are composed is definitely recognizable as country rock, the aggregate is commonly called *book structure*. When they are thin films or septa lacking the texture or appearance of country rock the term used is *ribbon structure*.[1]

[1] Still another type of banded structure (not discussed in this paper) is that for which Posepny proposed the term *crustification*. (Posepny, Franz, The Genesis of Ore Deposits: p. 11, Am. Inst. Min. Engrs., New York, 1895.) Some authors, especially earlier writers, have applied the term ribbon structure to crustification but such usage is no longer common. In a crustified vein the bands of gangue and ore minerals clearly represent successive stages of open-space filling beginning at the walls and proceeding inward toward the center. Although crustification is characteristic of epithermal veins, some semblances of it, notably comb quartz, occasionally appear in meso- and hypothermal veins.

Excellent illustrations of book structure and ribbon structure are to be found in readily accessible textbooks: Book structure in Lindgren's Mineral Deposits,[2] Figure 272, and Bateman's Economic Mineral Deposits,[3] Figure 12.9; ribbon structure in Lindgren,[4] Figures 45, 55 and 216.

Commonly both types of structure occur in the same vein and even in the same exposure; indeed, it is often possible to trace a book leaf along its trend and find it changing gradually into a ribbon as it becomes thinner and its original texture becomes obscure. As will appear later, we question whether the distinction between leaves and ribbons[5] is more than one of degree, but since the two types of structure have, in the past, been ascribed to contrasting modes of origin, the discussion will be clearer if we call the structures by different names.

As an inclusive adjective to describe both book and ribbon structure we suggest *laminated,* a term which mining men in various British countries have for many years applied to quartz veins of both types without implication as to either the composition or the origin of the interlayered bands. Accordingly the bands (both leaves and ribbons) might be called *laminae.*

Scope of the Present Investigation.—The theories of origin of laminated structure have been based largely on local interpretations. Thus the reader of the existing literature is asked to believe that book structure at Alleghany and Bendigo was formed by replacement, whereas on the Mother Lode it was formed by accretion; that ribbon structure at Grass Valley was formed by shearing of the quartz but that at Bendigo the ribbons are replacement residuals.

It would be futile, of course, to insist that all quartz veins in all districts had exactly the same history, for there must be many variations dependent on local conditions. But the gold-quartz veins of most mesothermal and many hypothermal districts have a multitude of features in common—more, in fact, than one would gather from reading the descriptions of individual districts written by different authors who call the same thing by different names, hold different theories of origin, and lay emphasis on different features. So striking are the similarities that no matter how plausible any theory of ribbon structure may seem to be for a given district, it is not wholly convincing, even for that district, unless it applies also to virtually identical structures in all districts. Surely, differences in origin, if they exist, should be reflected in recognizable differences in the products. Yet we are unable to find any features in the quartz of the Mother Lode, Grass Valley, Alleghany and Bendigo, for example, to indicate contrasting modes of origin. In short, the problem is not local but world-wide.

The present study of the problem began in the Porcupine district in connection with detailed studies of vein structure on scales ranging from large-

[2] 4th Edition, p. 666, McGraw-Hill, New York, 1933.
[3] P. 438, John Wiley and Sons, New York, 1942.
[4] Fig. 45, p. 157, Fig. 55, p. 171, Fig. 216, p. 549.
[5] By analogy to the term *book structure,* which refers to the aggregate of quartz and interlayered darker bands, it will be convenient to refer to the bands of country rock as *leaves* even though they may be of much greater than paper thickness. To keep a distinction clear the non-quartz bands in ribbon structure will be called *ribbons.*

scale underground mapping (by both manual and photographic methods) through hand specimens to microscopic sections. From this district inquiry was extended by field observations in other parts of Ontario and in Oregon, California, South Africa, Victoria and Western Australia. More recently it has been supplemented by study of many hand specimens and thin sections from a variety of districts.

NATURE OF RIBBONS.

The ribbons in a vein range in thickness from a barely visible line to several millimeters or, more rarely, a few centimeters. As a rule they are roughly parallel to each other and to the walls of the vein, even when the vein is curving or contorted in shape. The parallelism is approximate rather than exact, for branching at very acute angles is common and exceptionally two distinct sets of ribbons may cross each other, forming a network. In many veins the ribbons are more distinct and more closely spaced near the vein-walls than in the center.

As seen on an exposed surface, such as the face or back of a drift, some ribbons appear virtually straight, while others, on close examination, appear as irregular as the teeth of a saw, the sutures of an ammonite or the curves of a seismogram and it is perhaps significant that in some localities both the regular and the irregular type are visible in the same exposure and even in the same hand specimen. Figure 4 is an excellent illustration of the intricate crenulations seen in some ribbons. Ferguson[6] aptly terms the irregular structures "crinkly banding." In some specimens the crinkling is so minute that several jogs or undulations lie within a single field of the high-power microscope.

The shape of the "crinkly bands" in the third dimension is revealed by splitting the vein quartz along them. In some instances the surface has the appearance of slickensides, a fact which would at first suggest that the quartz had experienced faulting. But in some cases, at least, the slickensiding is earlier than the quartz deposition as indicated by study of such specimens from Porcupine.

Several of the small veins in the Hollinger mine consist of quartz 1 to 3 inches wide, each having a dark longitudinal suture in its center. When the vein is split open along the suture, the suture shows a slickensided surface marked by black alteration consisting of either chlorite or fine-grained tourmaline. In some examples the slickensided surface is discontinous because of a network of quartz veins crossing it. The quartz of these veins, however, merges with the massive quartz on both sides of the suture. In one example the slickensided surface is offset as though by a fault but there is no trace of a fault plane continuing into the enclosing quartz. Native gold, which occasionally occupies such slickensided surfaces, has the appearance of having been smeared on them but it is often difficult to be sure whether the gold has actu-

[6] Ferguson, Henry G., and Gannett, Roger W., Gold quartz veins of the Alleghany district, California: U. S. Geol. Survey Prof. Paper 172, p. 79, 1932. (As the introduction to the Professional Paper explains that the senior author was responsible for the description of the general geology and ore deposits, we shall credit statements in these portions of the paper to "Ferguson.")

ally been smeared or whether it merely has been molded by deposition in the slickensided slip.

Similar "fossil slickensides" have been described by Wilson[6a] at the Lamaque mine in Quebec: "Most strong veins have a conspicuous slickensided surface on their hanging-wall side, and they have a rude banded structure due to the occurrence of discontinuous slickensided surfaces that are marked by thin black seams. The vein material frequently cuts across the smaller slips within the vein, showing that movement took place before the vein material was introduced and that they (the slips) represent unreplaced pre-ore structures."

By no means all of the ribbon surfaces look like slickensides, however. Some are made up of small shallow cuplike depressions and domelike protrusions. Some are rough and puckered, with a shape reminiscent of a foliation plane in a coarse schist in which micaceous laminae bulge around phenocrysts of albite or other minerals. Surfaces of this shape are found even in ribbons that can be traced laterally into inclusions of even-bedded or smoothly cleavable slate.

While the thinner ribbons, whether straight or sinuous, look to the unaided eye like mere dark lines, the microscope reveals them as layers of mineral matter. In all of the cases that we have observed they are composed of the same minerals that constitute the altered rock of vein-walls and inclusions. Carbonate, commonly ankeritic, usually is the most abundant mineral and is accompanied by either sericite or chlorite. The flakes of the micaceous minerals are usually aligned parallel to the trend of the ribbon. Pyrite is common, usually in small anhedral or euhedral grains but occasionally in streaks parallel to the ribbon. Where arsenopyrite is present in the wall rock and veins (as at Alleghany and Bendigo) it is likely to appear in the ribbons. Other sulphides and gold are occasionally present. At Porcupine tourmaline has been observed and at Alleghany Cooke reports rutile.

Where the wall rock is serpentine, the micaceous flakes in the ribbons, like those in the recognizable inclusions in the vein, often prove to be mariposite. Where the wall rock is carbonaceous slate, as in Bendigo and in some Porcupine veins, the ribbons contain parallel streaks (films) of carbonaceous material. A thin section usually shows that a ribbon of this latter type consists of a dark, roughly medial line bordered on both sides by sericite or carbonate, the entire width of the ribbon measuring less than 1 mm. These borders are so common that considerable search was required in order to find the example shown in Figures 2 and 3 of a dark septum in quartz without any bordering carbonate or sericite and even in this instance the dark line can be traced laterally into its more normal environment.

The quartz immediately bordering a dark septum is generally fine-grained vein-quartz, a relationship which is also shown in Figures 2 and 3. Ribbons in a carbonate area are almost always more complete and more distinct in outline than those encased solely in quartz. Where dark septal streaks extend from a carbonate or sericitized area into vein quartz, as in Figure 2,

[6a] Wilson, H. S., Lamaque Mine: Structural Geology of Canadian Ore Deposits: Canadian Inst. Min. Metallurgy, p. 888, 1948.

they commonly become less distinct or narrower. Some fade out entirely or become lines of disconnected dashes.

The boundaries between ribbons and the enclosing quartz are characteristically irregular in microscopic detail and the quartz grains on opposite sides of the ribbons generally are not continuous with each other either in shape or in optical orientation. Thus the ribbons give the impression of going around the grains rather than through them and appear to weave their way between the grains of the quartz mosaic. Very exceptionally, however, we have noted cases in which areas of quartz on opposite sides of a thin ribbon were apparently parts of a single grain, continuous in optical orientation and without any faulting of grain-boundaries by the ribbon.

THEORIES AS TO ORIGIN.

As already intimated, there is considerable difference of opinion regarding the origin of laminated structures. As most authors regard book structure and ribbon structure as separate phenomena, it will be convenient to discuss under separate headings the theories of origin for each, even though it is believed that the difference between the two structures is merely one of degree. The principal theories as to the origin of book structure may be grouped according to whether they advocate (1) accretion or (2) replacement; theories as to the origin of ribbon structure may be grouped under (1) post-quartz shearing, (2) accretion or (3) replacement.

Theories as to Origin of Book Structure.

Accretion.—Most observers have ascribed book structure to successive reopenings of the vein-fissure, a concept proposed for the Mother Lode by Ransome,[7] adopted by Knopf [8] and ably developed under the name "accretion" by Hulin.[9] According to Hulin, book structure develops through "countless reopenings of the vein fissure contemporaneous with the mineralization, each opening tearing loose a thin film of the foliated wall rock which had frozen to the vein. The reopenings here commonly tore through the wall rocks rather than through the vein due to the greater strength of the vein matter. . . ."

Most authorities ascribe reopening to a continuation or resumption of the same force that opened the original fissure. Thus, Hulin [10] attributes it to recurrent movement and Johnston [11] even more explicitly postulates small fault displacements, parallel in general to the vein walls, forming openings of lenticular shape at points of minor irregularity. Hurst,[12] however, invokes tensile stress in the reopening of the Porcupine veins.

[7] Ransome, F. L., Mother Lode District, California: U. S. Geol. Survey Folio 63, p. 7, 1900.
[8] Knopf, Adolph, The Mother Lode System of California: U. S. Geol. Survey Prof. Paper 157, p. 25, 1929.
[9] Hulin, C. D., Structural control of ore deposition: ECON. GEOL., vol. 24, p. 30, 1929.
[10] Hulin, op. cit., p. 30.
[11] Johnston, W. D., Jr., The gold quartz veins of Grass Valley, Calif.: U. S. Geol. Survey Prof. Paper 194, p. 61, 1940.
[12] Hurst, M. E., Vein formation at Porcupine: ECON. GEOL., vol. 30, p. 115, 1935.

Other writers have called on the force of crystallization, as first suggested for the Mother Lode by Becker and Day [13] and vigorously advocated by Taber.[14] Knopf concludes that part of the "ribboning" (sic) on the Mother Lode "may be the result of laminae of schistose slate that incompletely filled a vein fissure or adjoined the fissure having been pried apart by the force of crystallization of the growing quartz."

Still others have attributed opening to pressure of ore-bringing fluids. Farmin,[15] although not accepting the concept of successive reopening, believes that "In effect, the country rock has been inflated along innumerable partings by the emplacement of the veins."

Replacement.—As contrasted with origin by either accretion or inflation, origin of book structure by replacement has been advocated by Howe, Dougherty, Stillwell, Ferguson and Cooke. Howe pictures the space between the hanging wall and the footwall of a fissure as filled with crushed country rock traversed by "walls" that resemble the main fissure walls. "Solutions permeated the mass of crushed country rock between the secondary fissures . . . and each rock fragment surrounded by a film of the replacing solution, became a center of attack. . . . In the great majority of the quartz veins, . . . replacement ceased before all of the fragments had disappeared, so that they are now preserved as inclusions. . . . The thin streaks of country rock which lie parallel to the walls in many cases are undoubtedly films of what once was gouge. . . ." [16]

Shortly after Howe's paper appeared, Dougherty proposed that: "The Porcupine quartz veins have been formed by the insinuating penetration of numerous tight or very narrow fissures and replacement of the contiguous rock." [17]

At Alleghany, Ferguson [18] suggests a mechanism somewhat similar to Howe's: ". . . replacement occurred largely in gouge along the fault planes and only to a minor extent in the solid rock . . . the smaller particles would be completely replaced, while the larger rock fragments . . . would be replaced to a less extent."

Cooke,[19] in a study of the Sixteen-to-One vein at Alleghany, appears to invoke a combination of accretion and replacement: Faulting forms shears on the margin of a growing quartz vein; quartz is deposited in open spaces and

[13] Becker, G. F., and Day, A. L., The linear force of growing crystals: Washington Acad. Sci. Proc., vol. 7, pp. 283–284, 1905.

[14] Taber, Stephen, Mechanics of vein formation: Am. Inst. Min. Met. Eng. Trans., vol. 61, p. 19, 1919.

[15] Farmin, Rollin, Host-rock inflation by veins and dikes at Grass Valley, California: Econ. Geol., vol. 36, p. 159, 1941.

[16] Howe, Ernest, The gold veins of Grass Valley, California: Econ. Geol., vol. 19, pp. 616–617, 1924.

[17] Dougherty, E. Y., Mode of formation of the Porcupine quartz veins: Econ. Geol., vol. 20, pp. 660–670, 1925.

[18] Ferguson, Henry G., and Gannett, Roger W., Gold quartz veins of the Alleghany District, California: U. S. Geol. Survey Prof. Paper 172, p. 80, 1932.

[19] Cooke, H. R., Jr., The Original Sixteen to One gold-quartz vein, Alleghany, California: Econ. Geol., vol. 42, pp. 229–232, 1947.

Cooke, H. R., Jr., The distribution of gold in the Original Sixteen to One vein, Alleghany, California: Thesis, Harvard University, 1944, p. 177.

by replacement of rock adjoining the shear and thus by progressive repetition the vein grows from the center outward.

Theories as to the Origin of Ribbon Structure.

Post-Quartz Shearing.—The most commonly accepted theory of the origin of ribbon structure is the one proposed by Lindgren who, in his enumeration of types of banding at Grass Valley, included: "3. Banded structure by subsequent movement on the vein, or *ribbon structure* proper. This form is extremely common, but has rarely been recognized as due to sheeting of the vein after its deposition." [20]

Howe [21] accepts this explanation for Grass Valley, apparently drawing a distinction between ribbons and the "thin streaks of country rock" which he interprets as replacement remnants.

Lindgren's explanation has been adapted to Alleghany by Ferguson [22] who attributed ribbon quartz to later fracture followed by deposition of still later minerals along closely spaced planes. Johnston [23] appears to use "ribbon quartz" and "sheared quartz" as though they were synonymous terms and offers "strain shadows" and "granulated quartz" as evidence of shearing.

So firmly rooted is the concept of post-quartz shearing that even where there is no physical evidence of deformation some authors have felt obliged to postulate it anyway and assume that the former evidence has vanished. For example, to quote from Adams: "An interesting example of *complete recrystallization* [italics ours] is found in a specimen of ribbon quartz from the Sons of Gwalia mine. The rock is a compact, brittle quartz with closely spaced sheeting planes surfaced by sericite and a little calcite. Under the microscope the quartz shows no crushing or fracturing, nor are the individual grains strained so as to present undulatory extinction." [24]

The gradation along strike or dip from bands of identifiable country rock (book structure) into the films or sheets that characterize ribbon structure is too common or characteristic to have been ignored. The customary explanation is that the bands of wall rock have served as bookmarks, so to speak, for localizing post-quartz shearing. Ferguson,[25] however, does not believe that all ribbons are localized by this means. "Elsewhere the fractures forming ribbons are closely spaced planes . . . or the bands may ramify irregularly through the quartz."

Accretion.—The mechanism of accretion which has already been discussed in connection with book structure also has been applied to ribbon structure. Knopf, particularly, advocates this method although he says,[26] "In places the slate ribbons have been sheared by movement during a subsequent reopening of the vein."

[20] Lindgren, Waldemar, The gold-quartz veins of Nevada City and Grass Valley, California: U. S. Geol. Survey, 17th Ann. Rept., pt. 2, p. 129, 1896.
[21] Howe, Ernest, op. cit., p. 599.
[22] Ferguson and Gannett, op. cit., p. 35.
[23] Johnston, op. cit., p. 31, p. 41.
[24] Adams, Sidney F., A microscopic study of vein quartz: ECON. GEOL., vol. 15, p. 651, 1920.
[25] Ferguson, op. cit., p. 36.
[26] Knopf, Adolph, op. cit., p. 25.

Replacement.—The possible origin of ribbon structure through replacement apparently has received little consideration, even from those who favor replacement origin for book structure. One of the few who carry the replacement idea through to what might seem to be its logical conclusion is Stillwell,[27] who, in fact, does not appear to draw the distinction implied by the terms book and ribbon but uses the mere general term laminae. The thinner laminae which others would call ribbons he regards as accumulated residue from replacement of beds or cleavage folia in slates.

OBJECTIONS TO PROPOSED THEORIES.

Objections to the Accretion Theory.—Some of the difficulties of the accretion theory are enumerated by Stillwell [28] in discussing Dunn's application of it at Bendigo. He says: "this explanation, involving successive openings and successive scalings of the wall rock, is confronted by grave difficulties. . . . The wavy tortuous course pursued by some of the laminae, the appearance of groups of laminae with frayed-out ends, the reappearance of such groups across areas of white quartz, the association of gold and minerals on both sides of the laminae, and the microscopic characters of the laminae are unexplained."

As this criticism suggests, the accretion theory would be more convincing if there were better evidence that the bands of quartz actually were deposited at successive stages. Were the theory applicable, one would expect to find visible differences in the quartz of different bands, since they have formed at different times and under at least slightly different conditions. Thus there should be a progressive variation from center to margin or from one side to the other, depending on the manner in which the vein had "grown." One would expect, furthermore, that where a dark band could be traced to its extreme termination the quartz would not be continuous around its end, but that a contact between the strands would be discernible. Where minerals other than quartz were present, one would expect to find consistent differences in the sequence, proportions, or form of the minerals in different bands. These conditions are not fulfilled in most veins that show book structure. Exceptionally, two, or at most a few, types of quartz can be distinguished, but, even so, their positions do not accord consistently with the sequence postulated by accretion. In general, the quartz strands, except in the immediate margins of the dark bands, are identical regardless of the position in the vein that they occupy.

Objections to the Post-Quartz Shear Theory.—Although it has become conventional to explain ribbon structure by postulating a period of shearing following deposition of quartz (and usually preceding the deposition of nonquartz gangue minerals, as well as most sulphides and gold), no proponent of this faith has offered a plausible mechanism to explain the shearing. Why in particular should shear failure take place *within* a quartz vein rather than along

[27] Stillwell, F. L., Replacement in the Bendigo quartz veins and its relation to gold deposition: ECON. GEOL., vol. 13, p. 105, 1918.

[28] Stillwell, F. L., Replacement in the Bendigo quartz veins and its relation to gold deposition: ECON. GEOL., vol. 13, pp. 103–104, 1918.

FIG. 1. Well developed ribbons in quartz vein, consisting of sericite and carbonate with minor sulphides and opaque specks. Alleghany, Calif., after Ferguson, U. S. Geological Survey.

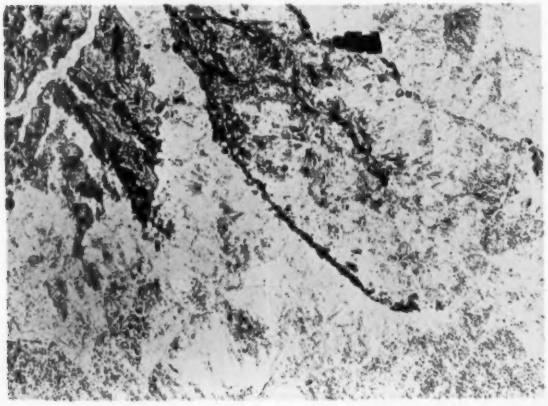


FIG. 2. Microscopic view of a dark septum passing out of a sericitized area into quartz. Alleghany, Calif., Sixteen to One Mine. X 26.5 One nicol.

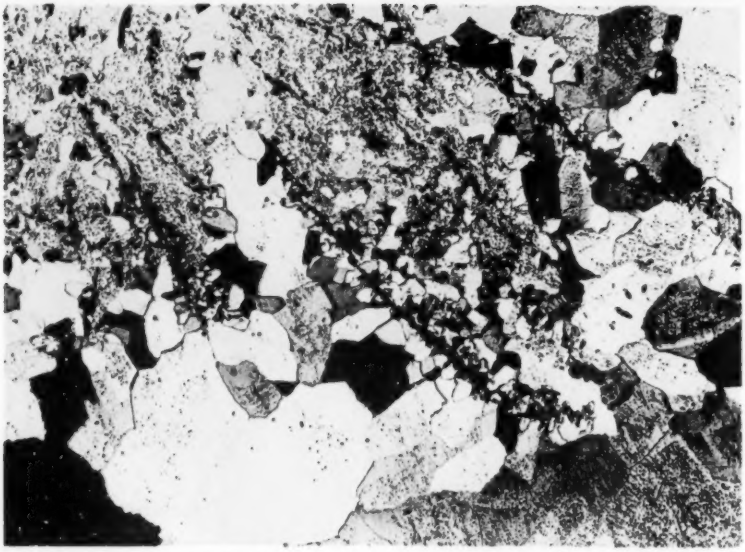


FIG. 3. Same as Fig. 2 with nicols crossed. Note fine grained quartz bordering dark septum and surrounded by coarse quartz.

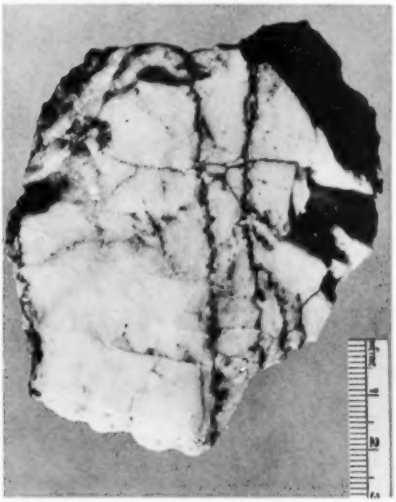


FIG. 4. Specimen illustrating the extreme crenulation common in some ribbons. Sixteen to One Mine, Alleghany, Calif.

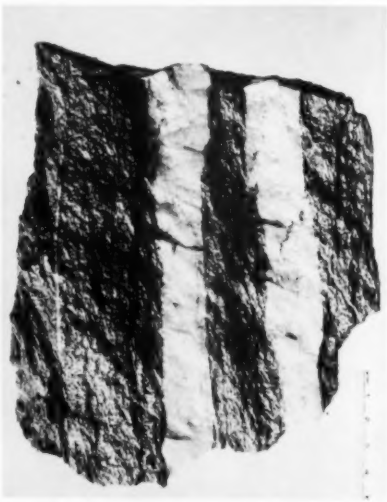


FIG. 5. Incipient stage in development of ribbon structure (from sheeted rock in a zone of tension fractures). Bendigo.

its walls despite the fact that in most districts the quartz is obviously stronger than the adjoining wall rock? If, in the early stages of vein deposition, when book structure was supposed to be forming by accretion, the superior strength of the vein matter caused the reopenings to tear through the wall rock (Hulin's explanation of book structure), is it likely that in the later stages, when the vein was even thicker and stronger, the failure would seek out the quartz vein in preference to the walls? Surely no evidence of such extraordinary behavior is to be seen in the mechanically analogous situation in which a hard dike occurs between soft walls or a quartzite bed occurs between slates. The only plausible explanation which the advocates of post-quartz shearing have proposed is that shearing has been localized along the leaves of book structure; yet book structure has not universally been considered a pre-requisite to ribbon structure. Even if the vein is conceded to be vulnerable to shear, why should post-quartz fractures orient themselves parallel to the vein walls, especially in a vein that executes sinuous curves?

The details of ribbons present still further obstacles to the shear hypothesis. Where ribbons appear as discontinuous lines of short dashes and where the dark septa fail to extend outside of carbonate areas into the quartz, these particular ribbons, at least, can hardly be post-quartz shears.

Moreover, the minerals of the ribbons pose a problem in timing, since the materials that form them are in general the same minerals that constitute the altered wall rock. If these materials were introduced after the quartz had crystallized and suffered shearing, the implication is that either there were two generations of each of these minerals or else the alteration of the walls was accomplished after the quartz was deposited, certainly the reverse of the accepted order. Granting, for the sake of argument, that the material of the ribbons is of late introduction, we are asked to believe that, in district after district, a period of shear-fracturing chanced to occur just after the quartz had been deposited but before the entry of the solutions which deposited carbonate, sericite, and sulphides. If it be answered that shear-fracturing was a pre-requisite to the entry of "late" solutions, we may ask how the same "late" minerals got into inclusions in adjoining veins of massive quartz where ribbon structure is lacking.

The paragenesis would be even more involved if, while ascribing the ribbons to post-quartz shearing, one were to accept the source of vein-quartz that Knopf proposes for the Mother Lode, namely derivation of silica from the break-down of rock silicates during alteration. For in that case there would be one period of carbonate formation, active chiefly in the wall rock, and a second period during which carbonate deposited in fractures in the quartz which itself was a reaction product of the first step. That such a fortuitous sequence of events has repeated itself in district after district seems difficult to imagine.

Objections to the Replacement Theory.—Reluctance to credit replacement with an important role in the genesis of quartz veins seems to stem from certain considerations based on the shapes of veins and their inclusions and on the chemical and mineralogical nature of vein deposition and rock alteration. It will be pertinent to examine some of these considerations.

1. Common evidence that *some* parts of a vein or of a vein system are fissure fillings and the inference from this that *all* parts must be. The evidence usually cited in favor of open-space filling comprises: Comb-structure of quartz, vugs (whether still open or now filled with younger minerals), "matching" vein-walls, and angular breccia.

Vugs and comb-structure, although undeniably testifying to existence of open spaces, can nevertheless originate in connection with the replacement process. The conventional concept of volume-for-volume replacement calls for a delicate balance of dissolution and deposition. The volume deposited cannot ordinarily exceed the volume dissolved, as there would be no space for it, but there is no general law which precludes dissolution in excess of deposition, a process which can, and in some geological situations unquestionably does, yield open spaces. Therefore vugs in the midst of vein matter do not necessarily mean that sizable open spaces existed before the ore-bringing solutions began their work.

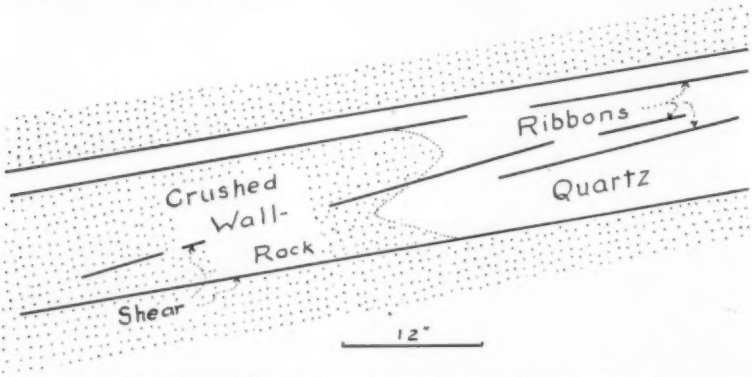


FIG. 16. Vein formed chiefly by replacement of crushed rock in a shear zone. Shears in the rock survive as ribbons in the quartz. Note: (1) continuity of outer walls of zone, (2) lack of displacement of rock-quartz contact by the shear. Norambagua Mine, Grass Valley.

Veins with matching walls, that is, walls that would fit together if the vein-matter were removed, are usually indications of open space filling, yet, especially if the veins are small, similar shapes can result from a wave of replacement that has advanced a uniform distance from a guiding crack. Such structures are commonplace among sulphides and other minerals, as seen under the microscope, and are not unusual on a larger scale. By the same process angular breccias can originate through replacement, as Bateman [29] showed many years ago.

Evidence of replacement is sometimes overlooked through misinterpretation of inherited breccia textures. A matching-mosaic structure in which the

[29] Bateman, Alan M., Angular inclusions and replacement deposits: ECON. GEOL., vol. 19, pp. 504–520, 1924.

fragments are now grayish or greenish quartz in a matrix of white quartz seems offhand to be evidence of two ages of quartz but actually the quartz may be of a single generation, the dark "inclusions" being silicified wallrock while the white matrix is quartz that fills open spaces between the original wall rock fragments. Such is Ferguson's interpretation [30] of breccias at Alleghany. Where replacement by quartz has been nearly complete, "the only difference between replaced fragment and surrounding vein quartz is in the presence of numerous small shreds of carbonate and sericite . . . and in places specks of sulphide minerals and minute indeterminable specks of opaque material."

Similarly, veinlets cutting transversely through book structure are not necessarily later than the quartz between the ribbons but may have filled an early fracture across the sheared but as yet unreplaced rock.

But despite the questionable nature of some of the evidence of opening and re-opening, the facts testify to plenty of open space filling in certain parts of many of these vein systems (Fig. 17). The significant point is that open space filling in one part of a vein is not evidence against replacement in another part.

2. Mineralogical and textural contrast between vein and altered wall rock. The idea of deposition of vein quartz by replacement of wall rock was vigorously opposed by Lindgren, who said: [31] "This proposition is advanced with considerable confidence: That aluminous rocks (shales, schists and igneous rocks) cannot be replaced by coarse-grained quartz without leaving abundant traces by structure, texture and relics," and later: "It is asserted that normal coarse-grained quartz cannot be formed by replacement of aluminous rocks." So far as we can find, Lindgren never set down his reasons for this opinion but his comments on the Porcupine veins may be revealing: ". . . it is a little difficult to account for a carbonate-pyrite-sericite alteration of country rock and a simultaneous silicification of other parts of the country, as the two are separated by sharp boundaries." [32]

As for the sharp boundaries, they are by no means uncommon in unquestioned examples of replacement. As Lindgren himself recognized in a general discussion of replacement: "Irving has pointed out that in some cases replacement begins from a great number of points in the rock . . .; the contact is then indefinite. In other cases the complete change occurs rapidly, advancing like a wave over the country rock; the contacts are then sharp." [33]

The chemical problem raised by Lindgren, however, does call for an answer. In the first place, one need not assume, as does Lindgren, that wallrock alteration and quartz deposition *were* contemporaneous; the sericite-chlorite-carbonate alteration in many districts seems best explained as an advance phase of the mineralization process with deposition of ore and quartz following on its heels.

[30] Ferguson, H. G., op. cit., p. 80.
[31] Lindgren, Waldemar, Magmas, dikes and veins: Am. Inst. Min. Met. Eng. Trans., vol. 74, pp. 83 and 91, 1926.
[32] Lindgren, W., Mineral Deposits, p. 666, New York, McGraw-Hill, 1933.
[33] Lindgren, W., Mineral Deposits, p. 180.

The chemical results of rock alteration at Porcupine are indicated by analyses published by Hurst, who shows that ". . . silica has actually been removed from the wall rocks" and that ". . . the aluminous content of the wall rock has remained practically unchanged even where alteration has been most intense." Hurst [34] regards these facts as evidence against enlargement of the Porcupine veins by replacement, a conclusion which seems to us a non-sequitur, but we do agree wholeheartedly with his statement: "it is evident that any enlargement of veins due to substitution of vein-quartz for wall rock must have been confined to and completely effected at the wall rock surfaces immediately in contact with the vein forming solutions"; we agree, that is, provided that we may be given a little leeway in the use of the word "immediately." The constancy of alumina content in wall rock during alteration is quite in accord with the well-recognized principle that under hydrothermal conditions alumina moves by diffusion relatively reluctantly. Consequently the rate at which alumina (and other replaced materials) can move out of their site by diffusion must place a limit on the distance from a channelway of circulation to which quartz can replace rock material in a given time, for replacement by quartz involves both outward diffusion of silica from channelway to rock and inward diffusion of replaced materials from their site to the channelway.

We are convinced that many of the perplexing problems of quartz veins are explainable if it be recognized that quartz is able to replace aluminous wallrock but can ordinarily do so only with slowness and difficulty. Suppose, for example, that in a given time replacement by quartz can penetrate only a few millimeters or at most a few centimeters away from a channelway. Then whole grains of gouge or slivers of country rock in a fault zone can be completely replaced if they are but a few millimeters thick and are surrounded by moving solutions capable of draining off the rejected products. Meanwhile quartz invades rock material in the wall of the shear zone only to the extent of the same few millimeters and thus nowhere deeply embays or corrodes the wall. Penetration is even more retarded if the wall is compacted by slickensiding or (in carbonaceous rock) encased by a film of graphite or hydrocarbon. Such a barrier would be conducive to a smooth sharp vein-margin lacking the obvious earmarks of replacement.

MODE OF ORIGIN BY REPLACEMENT.

It is the thesis of this paper that book structure and ribbon structure have a common origin; both structures originate through deposition of quartz or other gangue material in a zone which is already sheeted, schistose or sheared. Commonly the zone is a shear zone but alternatively it may be a thinly stratified sedimentary member like the black schist at Porcupine or certain carbonaceous argillites at Bendigo. Whatever open or potentially [35] open spaces

[34] Hurst, M. E., Vein formation at Porcupine, Ontario: ECON. GEOL., vol. 30, pp. 103–127, p. 113, 1935.

[35] By a "potential open space" we mean a fissure that was not a gaping void before ore deposition but was open when gangue was depositing. The apparent coincidence in time between the opening and the entry of mineralizing solutions may be explained in either of two ways:

existed served as channelways for flow of solutions and as starting places for replacement of the adjoining bands or leaves of wall rock. The laminae represent portions of the rock material that have survived replacement by quartz. If they become so thin or have been so completely converted into carbonate, chlorite, sericite, sulphides and other minerals that they are no longer recognizable as country rock they constitute ribbons.[36]

In accordance with the replacement theory the laminae may represent one or more of the following:

1. Slabs, slivers or leaves of country rock. The laminated structure may be inherited from cleavage, schistosity or bedding but in such cases the original structures usually have localized quartz by serving as loci for slipping and separation of the laminae. Intricately contorted ribbons in the Porcupine district clearly express partial replacement of complexly dragfolded carbonaceous slate (Figs. 18, 19). Not all laminated structure represents bedding or foliation, however, since book and ribbon structure are developed in veins traversing massive rock and, even in foliated rock, the laminae are more likely to be parallel to the vein walls than to the foliation if the two do not coincide.

2. Original slickensided surfaces within the shear zone. Along the slickensides, rock has been compacted and smeared with carbonaceous material, chlorite or sericite. Thus, a film has been created which is different from the adjoining rock in chemical composition or in permeability. If this film is less readily replaceable than the adjoining rock, it will remain as a "fossil slickenside."

3. Original gouge seams. Although we believe that gouge is generally readily replaceable because of its fine comminution, the suggestion has been offered (Howe) that laminae represent gouge and we cannot deny that under special conditions gouge may be less permeable, or for other reasons, less replaceable than the adjoining rock.

4. Stylolites. Some ribbons, when seen in cross section, look so much like stylolites that the possibility of analogous origin cannot be lightly dismissed. It is indeed conceivable that after quartz deposition has reached a certain stage the isolated book leaves are partly removed in solution whereupon collapse of the resulting open space would leave a thin film of residual material separating its original walls. We have not, however, recognized any ribbons for which this origin can be demonstrated convincingly.

5. Residues rejected from crystallizing quartz. It is well known that a growing crystal may either incorporate foreign matter as inclusions or reject it from the space which the crystal occupies. The rejected material may consist of solid particles which are not accommodated in the crystal structure,

(*a*) pressure of solutions was sufficient to separate the walls of those fissures which occupied a preferred position with respect to environmental forces; (*b*) solutions were able to enter and flow freely only when and as fracturing forces provided the openings. Whether solution pressure played an active or a passive role is not vital to the present discussion.

[36] This mode of origin is essentially that proposed by Stillwell for Bendigo. So far as book structure is concerned it is similar to that proposed by Howe for Grass Valley and by Ferguson for Alleghany. However, it was developed independently of any of these or at least without conscious influence by them.

or of laminae which are bodily shouldered aside. Alternatively, the rejected material may be in solution; as the growing crystal substracts silica from solution, the immediate environment becomes enriched in elements other than silicon. In the case of quartz encroaching from both sides on a sliver of rock, some of the rejected material is pushed ahead and accumulates as a film between the two layers of grains. As described by Stillwell,[37] "the replacement is pictured as extending from these channelways [openings in a slate bed] and pushing the insoluble residues toward the sides of the channels. If replacement is proceeding from two parallel channels, the dirt line from one channel will unite with the dirt line from the neighboring channel when replacement is complete."

If replacement is the active process in the formation of ribbons, all stages of replacement should be found. We believe that such is the case. We find all the steps from practically unaltered rock fragments surrounded by encroaching carbonate and quartz through various intermediate stages to the point where the ribbons are only grayish bands in which finely divided "indigestible" particles give the quartz a shadowy appearance. Ultimately even these shadowy "ghosts" of what was once ordinary country rock are erased and only milky white bull quartz occupies the space. Figures 5 to 11 are intended to illustrate the main steps in the process of ribbon quartz formation. Some of the specimens figured are from Porcupine, some are from Alleghany, and some are from Bendigo but the whole process seems to be common to all the ribbon quartz camps.

The specimen in Figure 5 illustrates the beginning stage in the process. Slabs of slatey quartzite are isolated in vein matter but still retain essentially their original character. The quartz areas are quite free of ribbons. Figure 6 shows the reverse side of the same specimen. Here the situation is quite different. Quartz and carbonate are seen to be eating into the slabs along the cleavage direction and slivers of as-yet-unreplaced rock are isolated in the mass of quartz and begin to look like ribbons. Certain laminae in the rock seem to be more susceptible to replacement than others as the vein material is advancing faster in some of them than in others. Some of the ribbon-like stringers are still attached to the parent slabs.

The next step in the process is the reduction of the isolated slabs to ribbons. Sometimes the replacement seems to move in waves working inward from the broad sides of the tabular fragments; elsewhere it seems to prefer to work on the broken ends. Figures 7, 8 and 9 show the ribbon-making job partly completed. There are still some well defined fragments that are obviously bits of country rock but they pass laterally into true ribbons. Figure 9 illustrates especially well the attack on the fragments from the broken end. This type of replacement, from the end rather than from the broad side, seems to give rise to more ribbons for a given amount of rock.

In Figures 7 and 8 there is relatively little clear white vein quartz. The narrow quartz bands between closely spaced septa are all shades of gray, the

[37] Stillwell, F. L., Factors influencing the gold deposition in the Bendigo Goldfield: Adv. Council Sci. and Ind. Austr. Bull. 8, p. 33, 1918.

quartz usually being darker the closer it is to a black band. In some places quartz has eaten its way across the thin streaks of carbonaceous matter leaving the ribbons as lines of short, disconnected dashes.

As replacement proceeds, the rock fragments gradually lose more and more of their identity. In Figure 10, of a Porcupine specimen, the "fragments" look about as much like ribbons as they do like pieces of country rock. From this point on, as replacement continues, the amount of ribbons and their striking appearance is on the decline. Figure 11 illustrates a step along the way between a well ribboned vein and clear essentially ribbonless quartz. Here the dark streaks are considerably less distinct than in the preceding pictures. All the original rock fragments have been erased and there are left only hazy streaks through the quartz which are due to concentrations of very fine, apparently indigestible particles. Some of the sharper ribbons here contain ankerite, sericite, fine pyrite, and gold.

It does not follow from this that all of the quartz, even in laminated portions of veins, is the result of replacement. Some of it (precisely what proportion in any particular case we would not venture to specify) doubtless represents the filling of open spaces that have served as main channelways for circulation of solutions through the sheared or layered zone. Not only do we admit open space filling as an integral part of the vein-forming process but, as will appear later, we consider filling of opened tension fractures by gangue as an essential part of our favored mechanism.

Nor do we maintain that in all veins and all districts the quartz veins escaped later reopening or shearing, for it is not difficult to find examples of veins crossed at large or small angles by late fault zones. Where a vein has actually experienced shearing stress parallel to its walls it is only reasonable to expect that failure may occur by slipping along any laminations that may be present. Furthermore, there are unquestioned examples in which a quartz vein is made up of stringers of more than one age and type. What we maintain is that neither post-quartz shearing nor accretion is an essential step in the development of a laminated vein.

Role of Carbonate in the Replacement Process.—The remarks previously made might indicate that quartz always replaced wall rock directly but it is clear that, in some places at least, the encroachment of gangue upon wallrock is a two-stage process; carbonate replaces the wall rock, then quartz replaces the carbonate (Figs. 12, 13).

The position in the mineral sequence that carbonate (particularly ankeritic carbonate) occupies is seemingly not the same in all districts if the published interpretations are to be taken at their face value. In the Porcupine district, ankerite is clearly an early mineral. Rims of ankerite bordering wallrock inclusions are partly replaced by quartz, which encroaches along twinning bands in the carbonate and surrounds ragged rhombic inclusions of it.[38] At Bendigo also, rims of ankerite around wall rock inclusions and against vein walls are characteristic and in places this carbonate is cut or netted by replacement veinlets of quartz. Ferguson describes similar rims or fringes at

[38] Graton, L. C., McKinstry, H. E., and others, Oustanding features of Hollinger geology: Canadian Inst. Min. Metallurgy Bull., vol. 249, pp. 1–20, 1933.

Alleghany, but says: "Commonly [carbonate and mica] occur only as a narrow fringe at the border of the quartz. Inspection of a hand specimen showing such a fringe gives the impression that the carbonate is earlier or is contemporaneous with the quartz; the true relations can be seen only in thin sections." [39] Just what the "true relations" are is hard to gather from the text. It is true that some of the photomicrographs show definite veins of carbonate in quartz but whether this is carbonate of the same age as that of the "fringes" is not stated. In any case there is microscopic evidence in Alleghany thin sections of quartz replacing carbonate (Fig. 15).

Again at Grass Valley, Johnston reports no early carbonate stage but he does present convincing evidence of an important late carbonate sub-stage during which ankerite recemented quartz that had been brecciated.

It is suspected that early carbonate may be more common than the literature indicates, for there are at least three considerations that tend to obscure or confuse the question of sequence.

(1) A truly late generation of carbonate is very common in veins of all types. In many gold quartz veins the late carbonate is calcite although without doubt late ankerite and dolomite also occur, whether as a late introduction or merely as a rearrangement of carbonate already present (the propensity of carbonates to redissolve and reprecipitate is well known [40]). It is easy to assume that because some carbonate is late, all carbonate is late. (2) Since quartz fails under pressure by fracturing whereas carbonate tends to deform plastically by gliding or recrystallization,[41] veinlets of carbonate cutting quartz are common and afford a strikingly recognizable age-criterion whereas veins of quartz cutting carbonate are relatively rare, even where the quartz is later than the carbonate. (3) The entrenched belief that ribbons are shears cutting vein quartz points unavoidably to the conclusion that any minerals in the ribbons must be later than the quartz. We suspect that this consideration alone has been taken in some districts as sufficient criterion for late age of carbonate. To use the age of carbonate based on this criterion as evidence for the origin of ribbons is, of course, reasoning in a circle.

Although replacement by carbonate seems, in some districts at least, to have been an advance stage in the encroachment of quartz upon wall rock it is unlikely that a typical vein was ever essentially a carbonate vein awaiting replacement by quartz, for if it were, there should be expected more examples of such veins which had escaped replacement.[42] Rather, the replacement by carbonate was an advance wave in the attack of gangue upon rock; the positions captured by the carbonate were subsequently occupied by quartz as the attack advanced. If quartz overtakes the carbonate and assumes a position immediately adjacent to the wall rock, it may obliterate part or all

[39] Ferguson, H. G., op. cit., p. 46.

[40] Grout, F. F., Microscopic characteristics of vein carbonates: ECON. GEOL., vol. 41, p. 489, 1946.

[41] Griggs, David, Experimental flow of rocks under conditions favoring recrystallization: Geol. Soc. America Bull., vol. 51, pp. 1001–1022, 1940.

[42] A few quartz veins in the Porcupine district do change along their strike into veins essentially composed of carbonate. As a rule pure carbonate veins are not more than a few inches thick.

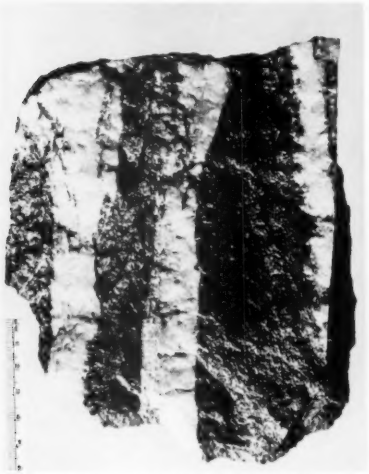


FIG. 6. Reverse side of Fig. 5. Quartz and carbonate are eating into slabs of slatey quartzite and some remnants begin to resemble ribbons.

FIG. 7. Slabs of country rock in part reduced to ribbons; fragments can be traced laterally into ribbons. Bendigo.

FIG. 8. Rock fragments being reduced to ribbons by replacement. In places quartz has eaten across thin streaks of carbonaceous material and left the ribbons as short disconnected dashes. Bendigo.

FIG. 9. Replacement attacking ends of a rock fragment. Note sides of the fragment are more resistant and tend to persist as ribbons. Bendigo.

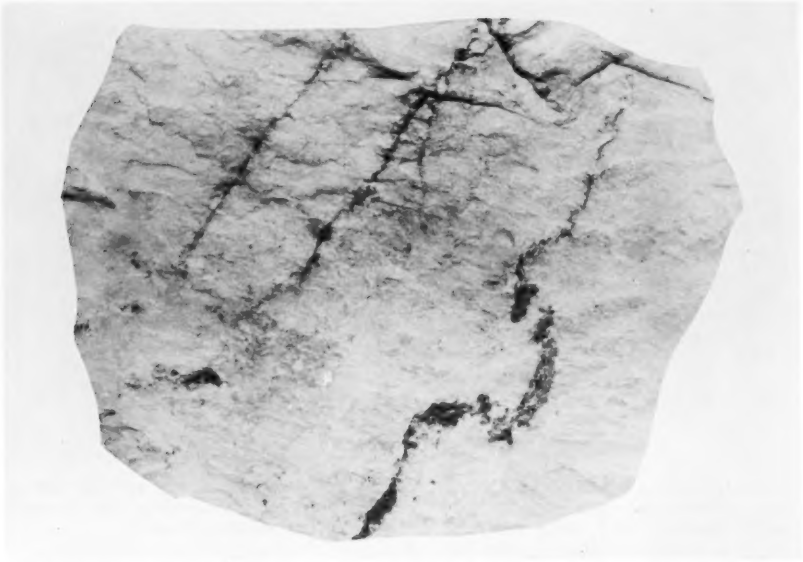


FIG. 10. Rock fragments have nearly lost identity and become mere ribbons. About the half-way point in the process. Porcupine.

FIG. 11. Specimen showing ribbons approaching obliteration by continued replacement. Porcupine.

FIG. 12. Rock fragments successively surrounded by carbonate and quartz. Close examination reveals that carbonate is replacing the rock and quartz is replacing carbonate. Bendigo.

of the evidence of an intervening carbonate stage. But where the process is incomplete the carbonate should record its history.

Thus, if ribbon structure is inherited from the original country rock or shear zone, ribbons should be present in the early carbonate as well as in the quartz that replaces it. Such in fact is the case. Indeed at Alleghany and Bendigo, if not elsewhere as well, ribbons are better defined and more striking within the carbonate areas than within quartz, as though the replacement of carbonate by quartz had partly erased the ribbons. Despite this tendency to partial obliteration, ribbons can usually be traced from carbonate into quartz and even through alternating areas of the two minerals (Fig. 2). It is noteworthy that in such cases the boundaries between the two minerals are not visibly displaced where the ribbons cross them.

EVIDENCE OF REPLACEMENT.

Much of the evidence favoring origin of laminated structure by replacement has already been presented by implication in discussing the inadequacy of other modes of origin and in describing the process as visualized. Additional evidence of a positive quality is to be seen both on a large and a small scale.

Shape of Vein-Walls.—The sharp regular vein-walls that are so often cited as evidence against replacement are by no means universal; highly irregular walls are not uncommon. It is difficult, for example, to interpret the irregular shapes of some veins in the Porcupine district, such as the one figured by Dougherty,[43] as the result of anything but replacement, however generous one may be in allowing for separation of the walls in some direction other than in the plane of the exposed face. In the Porcupine, Grass Valley and elsewhere there are structures like the one sketched (Fig. 16) in which a broad quartz vein changes abruptly to a horse of country rock, bounded by two slips, each of which is a continuation of the walls of the vein and one or both of them followed by quartz stringers. A significant feature of the vein depicted here is that what is a shear in the horse of country rock continues into the quartz as a ribbon, yet the boundary between crushed rock and quartz is not offset.

Replacement seems inescapable in structures like those illustrated in Figures 18 and 19 where quartz strands follow the intricately contorted bedding in a band of carbonaceous slate. The folds are of the same pattern as folds in the carbonaceous band where not quartz-bearing, a pattern which is part of the drag-folding accompanying regional deformation. Post quartz shearing could hardly produce fractures of this shape and it is difficult to visualize any process of accretion forming openings of such irregular yet consistent shapes. Conceivably folding of already formed ribbons[44] would be a possibility but there are independent reasons for the generally accepted conclusion that quartz veins in the Porcupine district were introduced after

[43] Dougherty, E. Y., op. cit., p. 663, Fig. 3.

[44] Ferguson suggests such an origin for "crinkly banding" at Alleghany. Ferguson, H. G., op. cit., p. 79.

folding was complete. With replacement there is no need to postulate recrystallization to explain away the lack of evidence of deformation of the quartz.

Distribution of Ribbons.—The greater abundance of ribbons near the margins of veins is to be expected if replacement is an important mechanism in vein formation. Laterally from the center of the main pre-quartz shear zone, the fracturing would be less intense, the spacing of the shears would be wider and the rock slabs would be correspondingly thicker. Thus, as the waves of carbonate and quartz replacement attacked the fragments, it would be expected that the thinner ones with higher ratio of surface to volume (and located, moreover, in the channel of greatest flow) would be "digested" first and the thicker ones near the margins of the zone would show an increasingly higher percentage of unreplaced material. In consequence of the greater replacement intensity in the more permeable central area, ribbons which once existed there would have been erased by complete replacement leaving an unribboned white quartz core while near the walls ribbons were still distinct.

Position of Laminated Structure in the Vein Pattern.—Another aspect of grosser vein structure which offers evidence of replacement origin of laminated structure is the position of this structure within the vein pattern of a district. A typical fracture system is a pattern made up of both shear fractures and tensional openings. In general, the shear fractures are either single tight seams, or zones of sheared rock (all gradations between these two extremes exist), whereas the tension fractures are open or potentially open fractures. Where the geometry of the vein-system is simple, as it tends to be in massive uniform rocks, there is one set (or sometimes a pair of complementary sets) of shear fractures together with a set of tension fractures that stand at a small angle to the shears. The tension fractures may be visible as spurs or as zones of breccia making out from the shears or as distinct veins which either branch off from the shear zones or form connecting links between them. Fragments in the shear zones tend to be thin, platey slabs with tapering edges, more or less crushed and intermingled with gouge or pulverized rock; on the other hand, fragments in the tensional openings when present are likely to be thick, blocky and angular.

According to the concept of gangue deposition proposed here, solutions, when they traverse such fracture systems, utilize fractures of both types as channels of circulation. They deposit quartz and other gangue minerals by replacement (principally of rock fragments within the channelways of circulation) and by crystallization in open spaces. In the shear zones, which contain fragments presenting a great deal of surface area, replacement is relatively more prominent than in the zones of tension, hence laminated quartz is produced. The thickness and spacing of the laminae depend on (1) the spacing of the original shears, (2) the speed at which replacement proceeds and (3) the time throughout which the solutions are active.

Meanwhile, in the tensional openings mineral deposition by open space filling predominates, forming relatively clear veins with matching walls or else domino breccias cemented by vein minerals. Replacement is no less capable here than in zones of shear and in some cases may remove fragments in the

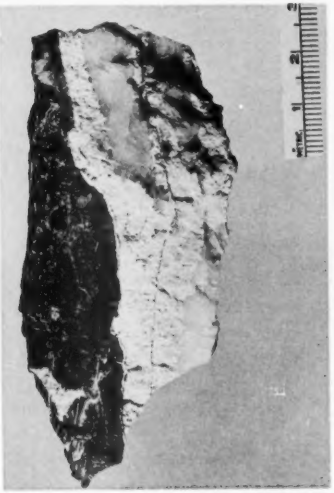


FIG. 13. Ribbon developed in carbonate (white) and preserved where the carbonate is replaced by quartz (gray). Bendigo.

FIG. 14. Quartz largely open space but with some replacement; dark broken fragment in center is surrounded by carbonate (lighter gray). Carbonate has also selectively replaced laminae in fragment and occupies space between three dark streaks.

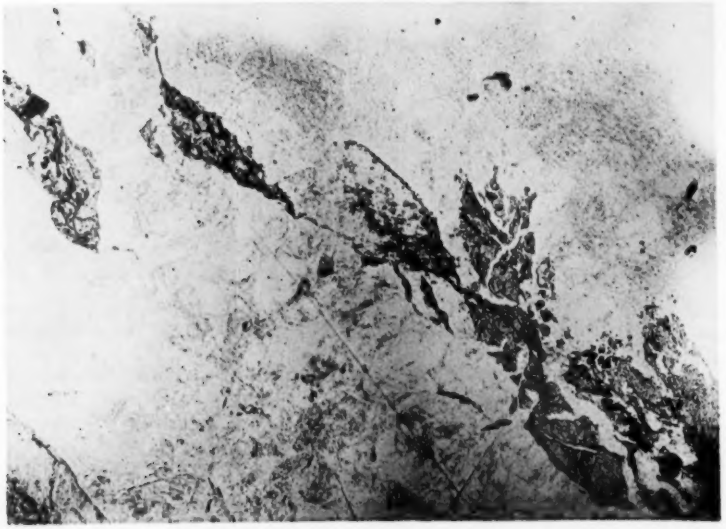
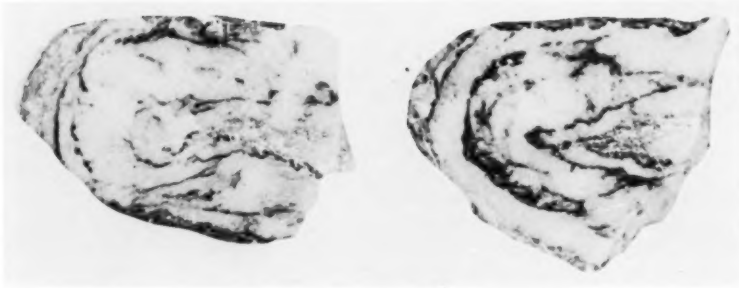


FIG. 15. Same thin section as in Figs. 2 and 3 and showing quartz veining and encroachment on seriticized wallrock fragments, left with moth-eaten appearance. X 12.



FIGS. 18 and 19. Apparently "folded" ribbons resulted from selective replacement of certain beds in a crumpled carbonaceous slate. Hollinger Mine. 18 is two-fifths natural size; 19 natural size.

channel (Fig. 6), but in general the uncrushed, more nearly equidimensional blocks offer such formidable opposition to replacement by the mineralizing solutions that they are left in relatively fresh condition after the surrounding openings have been filled.

Where the geometry of the fracture system is more intricate, either because the rock mass is inhomogeneous or the stress history is complex, an individual vein may swing from the shear direction to the tension direction and in so doing change from a laminated vein to inclusion-free quartz or to angular breccia. Some veins occupying intermediate attitudes consist of tension fractures arranged *en échelon* along axes which themselves are more nearly in the shear direction. Closely spaced tension fractures of this sort may form a sheeted zone which, when quartz-filled, approaches book-structure in appearance. Where these individual fractures stand at a small angle to the trend of the zone, the slabs of wall rock between them may have the form of "straps" which cross the zone diagonally and sometimes are broken.[45]

One or two examples may clarify further these structural relationships of laminated quartz.

At Woods Point in Victoria, flattish veins of two sets, dipping in opposite directions across a broad diorite dike, occupy a conjugate system of reverse faults and carry much laminated quartz. As any one of these veins is traced upward toward the margin of the dike, it flattens, thereby approaching the tension direction, and in so doing changes to a zone of quartz-filled fractures and breccia.

At Norseman, W. A., the vein system consists of steep shears of reverse fault movement connected by flatter linking veins, which in places curve into parallelism with the shears. Where the veins follow the shear direction they carry much laminated quartz; but where they swing to the flat tension direction they are zones of domino breccia (Fig. 17).

Again in the famous Bendigo reefs, the "backs" which represent reverse movement on bedding planes, are composed typically of laminated quartz, whereas the "spurs," occupying tension directions, as well as portions of the saddle reefs themselves, contain massive quartz and angular inclusions. Stone[46] finds that: "The generalization stated by McKinstry that fractures formed by shear (as contrasted with tension openings) are apt to be marked by ribbon structure is valid for Bendigo." It is notable that even in the saddle reefs, where angular inclusions are conspicuous, there has been a considerable, though undetermined, amount of replacement. For example, saddles like the one figured by Lindgren[47] can hardly be interpreted as simple open space filling.

The fact that, where the stress orientation is deducible from independent evidence, the shear elements are laminated and the tension elements are not, seems excellent evidence for the mode of origin that we have outlined. Were

[45] For excellent illustrations, see Farmin, Rollin, Host-rock inflation by veins and dikes at Grass Valley, California: ECON. GEOL., vol. 36, Fig. 2, p. 150, Fig. 6, p. 154, 1941.

[46] Stone, John B., The structural environment of the Bendigo Goldfield: ECON. GEOL., vol. 32, p. 884, 1937.

[47] Lindgren, Waldemar, Mineral Deposits, Fig. 224, p. 558.

ribboning due to later shear, no such correspondence would be expected unless it happened that the late shearing stresses had the same orientation as those which originally created the fracture pattern. But in that case the tension veins should either show late re-opening by tension cracks parallel to their walls and filled with the same minerals that formed the ribbons or else show ribboning crossing the tension veins at an acute angle, *i.e.,* paralleling the shear direction

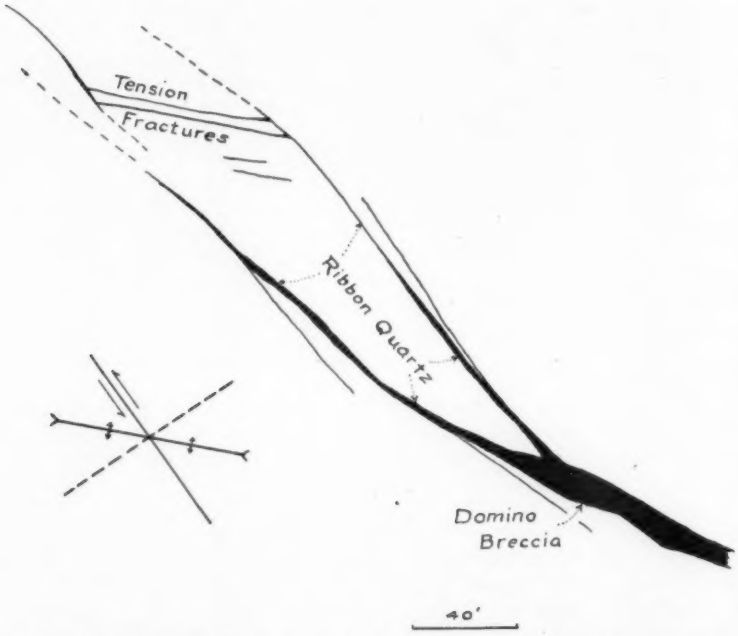


FIG. 17. Position of ribbon quartz in a vein system. Ribboned shear-fractures give place to domino breccia as vein swings from shear direction toward tension direction. Cross section looking north. Norseman, W. A.

of the stress pattern. No consistent relations of this nature have been described.

If ribbon quartz marks the shear direction, the relationship between stress and nature of quartz can obviously be put to use in identifying the shear and tension elements in a vein system whose mechanics is under investigation.[48] A further practical application derives from the fact that in some districts ribbon quartz is habitually richer in gold than is masive quartz. In certain cases (notably Norseman and at least one mine in Grass Valley), the most favored

[48] This correlation between laminated structure and shear directions fails in situations where the sheeting expresses bedding or pre-existing schistosity instead of fracturing.

attitude is intermediate between that of shears, which tend to be too "tight," and tension fractures, which are inclusion-free, an observation which may perhaps be explained by the greater area of wall rock surface presented to the solutions for chemical reaction or thermal interchange (in plain words, cooling). Whatever the explanation, one of the objectives in the search for ore in a district where laminated veins are notably favorable is to concentrate exploration on parts of the vein system in which the vein-attitude, as determined by drill intersections or other means, is a favorable one. Such an approach at Norseman was notably successful in reviving a temporarily abandoned mine.

Evidence from Detailed Nature of Ribbons.—Since ribbons are small features, so far as their thickness is concerned, conclusions as to their origin call for close-up study with the lens and the microscope.

As noted above it is quite characteristic for the quartz adjoining ribbons or lying between closely spaced ribbons to be finer grained than the quartz farther away from them. Some authorities [49] have attributed this fineness of grain to mechanical granulation and offered it as "exhibit A" to support the theory of post-quartz shearing. It is doubted, however, whether the fine-grained material is "granulated quartz"; instead it may be considered that the advance stage of replacement of wall rock or carbonate by quartz normally yields a fine-grained variety of quartz.[50] Grains begin to grow from many closely spaced centers in the host until further enlargement is limited by the interference of one grain with another. As the wave of replacement progresses, larger grains grow at the expense of smaller ones in accordance with a well-known principle. In the intermediate stages of growth-under-difficulties parts of the large grains remain imperfectly oriented and give patches of non-uniform extinction, sometimes misinterpreted as strain-shadows. Thus the process is exactly the opposite of "making little ones out of big ones." This is not to deny the existence of true micro-brecciation in certain places where the quartz actually has been fractured; we would not question some of the examples of brecciation figured by Lindgren,[51] Johnston,[52] and Ferguson.[53] Johnston draws a distinction, however, between "brecciated quartz" of this nature and the "sheared quartz" found along ribbons; so would we, though our interpretation would not be the same as Johnston's.

Where the dark wall rock constituting a book-leaf passes gradually into dark clouded quartz and then into clean quartz, the transition may take place over a distance of a few millimeters or exceptionally a few centimeters. Under the microscope the clouded quartz is seen to contain inclusions of alteration minerals of the wall rock as well as tiny specks too fine to be positively identified.

These gradual transitions are more common at the ends than at the sides of book-leaves. In some instances the transitional area is partly occupied by

[49] Lindgren, W., U. S. Geol. Survey 17th Ann. Rept., pt. II, p. 129, and p. 131, 1896. Johnston, W. D., U. S. Geol. Survey Prof. Paper 194, p. 41, 1940. Ferguson, H. G. and Gannett, R. W., U. S. Geol. Survey Prof. Paper 172, p. 41, 1932.

[50] Adams, S. F., op. cit., p. 653.

[51] Lindgren, W., U. S. Geol. Survey 17th Ann. Rept., Plate VIa, opp. p. 136.

[52] Johnston, W. D., U. S. Geol. Survey Prof. Paper 194, Plate 20.

[53] Ferguson, H. G., U. S. Geol. Survey Prof. Paper 172, Plate 36c.

tiny irregular veinlets of quartz which must be replacement veinlets, since the thickness of the book-leaf is no greater where they are present than where they are absent. Where quartz has attacked the book-leaves end-on in this manner, the margins of leaves are commonly the most persistent parts. Thus one or both margins of a leaf may continue out into the quartz and constitute a ribbon as shown in Figure 9.

In some instances one side of a book-leaf is a sharp line which continues as a ribbon beyond the point where the leaf itself has disappeared, while the other side of the leaf has the kind of fading boundary that more commonly appears at the ends of leaves. In other instances a leaf ends by tapering wedge-fashion into a ribbon. A ribbon may end either abruptly or by tapering, and beyond its end the quartz normally shows no sign of shearing.

Conclusive evidence of replacement as opposed to post-quartz shearing is available for at least one locality in a specimen from Bendigo figured by F. M. Chace.[54] A large euhedral crystal of arsenopyrite lies athwart a stylolite-like ribbon and on both sides of the ribbon the crystal is surrounded by quartz. Since arsenopyrite at Bendigo is shown by abundant independent evidence to be earlier than quartz, only one interpretation seems possible: A shear-plane or some other "indigestible" film existed in country rock and the crystal of arsenopyrite formed by replacement of the wall rock (and also of the shear-plane). Then the wall rock was replaced by quartz, preserving the shear-plane as a ribbon.

CONCLUSIONS.

The chief alternative hypotheses that have been advanced to account for book structure are accretion and replacement.[55] The chief alternative hypotheses that have been advanced to account for ribbon structure are post-quartz shearing, accretion, and replacement.

Without denying that either accretion or post-quartz shearing may have been operative in certain localities, it is concluded that the objections to both of them as essential mechanisms in producing laminated structure are insurmountable. Moreover, since neither of them by itself seems capable of producing both book structure and ribbon structure, the production of both types of structure in the same vein without the agency of replacement would call for a definite and complex sequence of events—a sequence which might by chance occur in one deposit but becomes more fortuitous and correspondingly less plausible as virtually identical laminated structures are recognized in district after district. Replacement, on the other hand, is a single process which can produce both book- and ribbon structure and do so in a continuous operation. Not only is it entirely in keeping with recognized processes of ore deposition, but it is consistent, as is no other process, with the features of veins as observed on all scales from the major vein-pattern down to microscopic detail.

[54] Chace, F. M., paper in preparation.

[55] A third hypothesis, inflation of rock structure by invading solutions, has not received detailed consideration in this paper because it calls for solutions having the nature of "ore magmas," the chemical improbability of which has already been emphasized by other authors.

ACKNOWLEDGMENTS.

We wish to thank Dr. L. C. Graton not only for giving generously of his time and skill during the preparation of photographs but for his less tangible though more fundamental contribution in the form of many discussions of the origin of veins. A basic thesis of the present paper—preservation of pre-existing structures by highly selective replacement—is a concept that he has advocated for many years. Dr. F. M. Chace has very kindly criticized the manuscript and on numerous occasions has discussed with us the processes of vein formation. The Bendigo specimens used in a number of the illustrations were collected by him. The Alleghany specimens were collected by H. R. Cooke, Jr.

ROTCH BUILDING, CAMBRIDGE, MASS.,
October 20, 1948.

SHEET STRUCTURE, A MAJOR FACTOR IN THE OCCURRENCE OF GROUND WATER IN THE GRANITES OF GEORGIA.[1]

HARRY E. LEGRAND.

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ABSTRACT.

Increasing demand for supplies of ground water in the Piedmont of Georgia has necessarily focused attention on granitic rocks, which have a considerable areal extent in this part of the state. These rocks have the property generally known as sheet structure. Major parting planes resulting from sheeting are usually sub-parallel to the rock surface on hills and in valleys and consequently control the circulation of subsurface water. Imperfect shallow pseudosynclinal basins formed by sheet planes in valleys are the receptacles for much subsurface water that percolates along these planes from nearby upland slopes. Therefore, wells drilled in lowlands in sheeted terranes almost invariably produce greater quantities of water than those on the uplands.

INTRODUCTION.

THE work on which this paper is based is part of an investigation of the ground-water resources of Georgia that is being made by the U. S. Geological Survey in cooperation with the Georgia Department of Mines, Mining and Geology. This work is being done under the direction of A. N. Sayre, Geologist in Charge of the Ground Water Division of the U. S. Geological Survey, and Garland Peyton, Director of the Georgia Department of Mines, Mining and Geology. Thanks are due S. M. Herrick, geologist of the U. S. Geological Survey in charge of the investigations in Georgia, who gave valuable suggestions during the study, and J. B. Mertie, Jr., also of the U. S. Geological Survey, who reviewed the manuscript.

[1] Published with the permission of the Director of the Geological Survey, U. S. Department of the Interior.

The occurrence of ground water in the Piedmont of Georgia depends upon many causes, some of which are closely related. The principles or factors which govern the occurrence of ground water in granites and closely allied igneous rocks may have regional application, whereas these principles, when applied to other crystalline rocks, may have only local significance. Rock type, structure, weathering, and topography are the significant factors. Sheeting is a fifth, but related, factor that is especially important in the occurrence of ground water in granite areas. The discussion of sheeting forms the major thesis of this paper.

Rock Type.—A classification of igneous rocks according to their mineral constituents reveals well-recognized rock types having properties which exercise only limited control in the circulation of water. Petrographic types are therefore considered relatively unimportant, because the constituent grains of all igneous rocks are so closely interlocked as virtually to deny access to ground water. Alteration of mineral composition and structure through weathering tends to modify this condition, as discussed later.

Structure.—Some modification of the massive igneous structure occurs in almost all bodies of crystalline rocks. The metamorphic rocks, owing to deformation, contain many structural planes, some of which affect the circulation and storage of ground water. The most prominent planes along which ground water moves are those due to foliation, which, in Georgia, generally trends northeast and dips steeply southeast. Other structural planes less systematically developed traverse the rocks at various angles. Such structural planes are either absent in the massive igneous rocks or are so poorly developed that water cannot readily circulate. The widespread occurrence of nearly flat-lying openings, however, constitutes a phenomenon of paramount importance, especially in granites. Such openings are the result of sheeting.

Weathering.—The crystalline rocks of the Piedmont of Georgia have been deeply weathered and are therefore covered by a rather thick mantle of residual material, commonly designated mantle rock. This surficial material furnishes appreciable storage space for ground water. The residuum is thickest in lowlands, owing to greater penetration of moisture there, and decomposition generally occurs more rapidly than the decomposed rock can be removed. The residuum is relatively thin or entirely absent on well-drained uplands, being thinnest on steep slopes.

Topography.—The rocks of the lowlands are believed by Furcron,[2] Mundorff,[3] and others to contain much more ground water than is to be found beneath the uplands, particularly in granite terranes. Available data appear to support this view. Probable causes for relatively copious supplies of ground water in the lowlands are as follows: (a) Less surface runoff and consequently more direct influent seepage occurs in the valleys, owing to the flatter terrain and thicker residual material to receive the water. (b) Influent seepage occurs from upland surface runoff, only part of which is confined to chan-

[2] Furcron, A. S., Geology and mineral resources of the Warrenton quadrangle, Virginia: Virginia Geol. Survey Bull. 54, p. 72, 1939.

[3] Mundorff, M. J., Progress report on ground water in North Carolina: North Carolina Dept. Cons. and Devel., Div. Min. Resources Bull. 47, p. 16, 1945.

nels. (c) Influent seepage occurs from upland rock slopes beneath the residual material. This is especially important in sheeted terranes. The gradient of the water table is, of course, toward the lowland, resulting in continuous recharge there. (d) Greater void space is available for storage of ground water, owing to the greater thickness of residual material. (e) Some valleys are associated with faults and other major parting planes along which water circulates, and in some areas this factor doubtless is more important than any other in regard to the availability of ground water. Most valleys, however, especially those in homogeneous rocks of great thickness, appear to have no relation to structural planes other than those due to sheeting.

SHEETING IN THE GRANITES OF GEORGIA.

Some igneous rocks develop subparallel parting planes called sheeting, or large-scale exfoliation, that is approximately parallel to the surface of the land. Sheet planes, though present in many metamorphic rocks, are more or less obscure, as they are obliterated or generally masked by inherent structural planes. Also, in many instances the presence of structural parting planes of low dip in metamorphic rocks precludes the necessity for relief of tensional stresses through the formation of sheet planes, these stresses being relieved by the development of openings along the existing planes. The sheet planes therefore coincide with the structural parting planes in metamorphic rocks of low dip.

Massive igneous rocks having little or no structure appear to be particularly susceptible to sheeting. The granites exhibit sheeting in the highest degree. Igneous rocks of low silica content, such as gabbro, pyroxenite, and peridotite, generally show sheet structure less prominently than those of high silica content.

Some degree of linear, or platy, structure can be seen in practically all the granitic masses of Georgia, including Stone Mountain in DeKalb County; yet this structure, generally in the form of parallel arrangement of micaceous minerals, rarely yields any planes of parting. Sheet planes are independent of such structures.

In this discussion the granites of Georgia may conveniently be classed in two groups irrespective of their compositon, texture, or age: (a) Large bodies, the outlines of which are either discordant or only faintly concordant with that of adjacent rocks and showing little or no relation to regional structure; (b) smaller, lenticular bodies that have been injected into a host rock and form with the host rock an injection complex in which the granite cannot practicably be mapped separately. Sheeting appears to be better developed in the larger masses of granite and it is with these masses that we are concerned.

The dome of granite at Stone Mountain provides an excellent example of sheeting as developed in a large granitic mass (Figs. 2, 3). The rock composing the mountain is a medium-grained light-gray granite, showing only slight variation in composition and texture. Above the sculptured figure of General Robert E. Lee's horse on the steep north slope, sheeting planes are parallel to the surface slope. Below this area the surface of the dome steepens,

allowing the sheet planes to crop out as discontinuous scars. Elsewhere on the mountain they are essentially parallel to the surface. The tendency toward parallelism of sheet planes with the surface of the ground exists also in depressions. This is shown half a mile north of Stone Mountain, where the sheets are essentially flat, becoming concave upward toward the dome.

A highly contorted gneissic granite that occurs at Lithonia, 10 miles south of Stone Mountain, is another example of a large granitic mass in which sheeting is well developed. The gneissic character of this rock is displayed through the parallelism of thin bands of biotite, which alternate with layers of feldspar, quartz, and accessory minerals. This granite, however, does not part along the platy micaceous bands, but splits instead along the planes of sheeting. The lack of parting planes along the micaceous bands is due to the absence of parallel orientation of the platy micaceous minerals.

The frequency of sheeting planes with increasing depth cannot be predicted. Jahns [4] states that in the granites of New England the sheets generally become thicker, flatter, and more regular with increasing depth. Sheeting is known to extend to a depth of at least 320 feet at Quincy, Massachusetts.[5] All observed granite quarries in Georgia exhibit sheeting to the bottoms of the existing openings, the deepest of which is approximately 150 feet deep. The thickness of individual granite sheets ranges from a few inches to several feet. The voids between sheets become progressively thinner with increasing depth, making the occurrence of appreciable quantities of ground water less likely at depths greater than 250 feet.

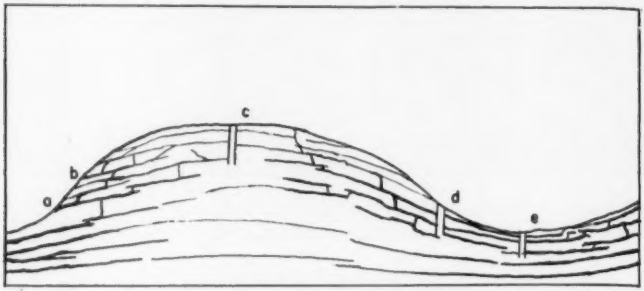

FIG. 1. Cross section of sheeted terrane showing water-filled joints in heavy dark lines. a. perennial sheet spring; b. intermittent sheet spring; c. unsuccessful well; d. successful well; e. possible flowing well.

CAUSES OF SHEETING.

The causes of sheeting in the southern Appalachians still are not well understood. The most widely accepted explanation attributes sheeting to weathering or erosion or a combination of the two. More specifically, the

[4] Jahns, R. H., Sheet structure in granites: its origin and use as a measure of glacial erosion in New England: Jour. Geology, vol. 51, p. 78, 1943.
[5] Idem, p. 77.

FIG. 2. (Upper) Sheeting in Stone Mountain quarry, northeast slope.
FIG. 3. (Lower) Sheeted zone on eastern slope of Stone Mountain.

causes of exfoliation [6] would include [7] (a) hydration of the feldspar to form kaolin and the resultant expansion of the rock, (b) seasonal changes of temperature, causing contraction and expansion of the rock, and (c) expansion of the rock owing to the relief of internal pressure through removal of overlying material by erosion, resulting in tensional forces that cause exfoliation.

It appears unlikely that hydration of feldspars and the resultant expansion can be the actuating factor in sheeting where little or no apparent tendency

[6] Some geologists, including the author, employ the terms exfoliation and sheeting interchangeably, while others attempt to differentiate between these terms. In the latter case the distinction apparently is made on the basis of magnitude. Exfoliation, therefore, is sometimes applied to small-scale parting planes.

[7] Lobeck, A. K., Geomorphology, 1st ed., p. 85, McGraw-Hill Book Co., 1939.

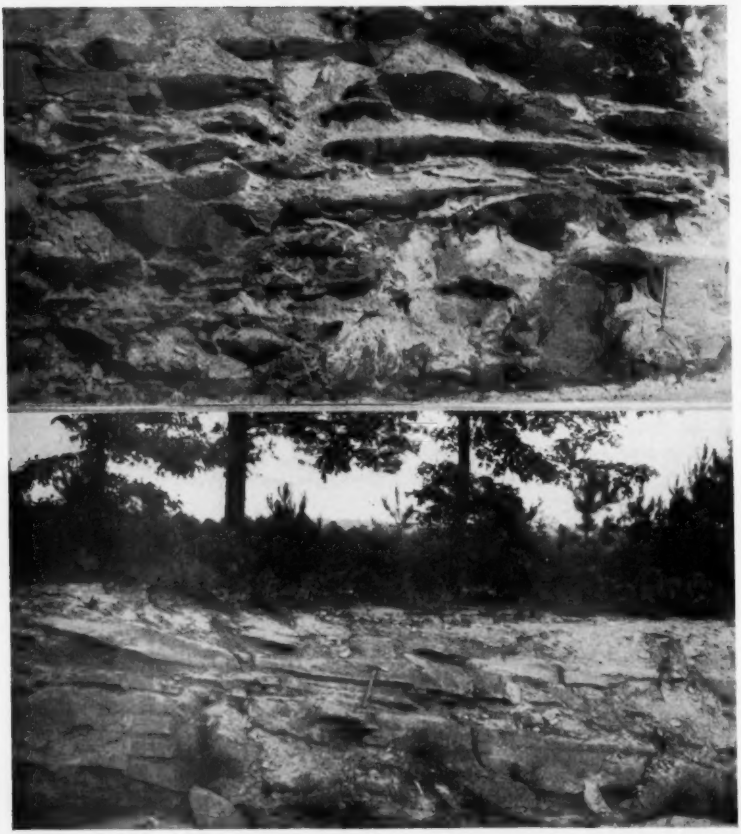

FIG. 4. (Upper) Sheeted granite in road cut, Forest Park, Georgia, showing alternating layers of fresh granite and enlarged saprolitic sheet planes.

FIG. 5. (Lower) Sheet structure in granite 3 miles east of Red Oak, Fulton County, Georgia.

toward kaolinization exists. Nevertheless, after these planes have been formed, the penetration of moisture along them has, in partially weathered exposures, resulted in their enlargement to form zones of soft saprolite. This condition is so strongly developed in most of the granites of Georgia that the zone of weathering displays alternate layers of fresh rock and saprolite as pseudoanticlinal and pseudosynclinal flexures that are subparallel with the surface of the ground but with less relief (Figs. 1, 4).

Changes in temperature probably represent a contributory factor in surficial partings but can hardly account for the deep-seated sheet structure in the granites of Georgia and of other regions.

Erosion has resulted in the removal of many hundreds of feet of materials overlying the existing granites of Georgia. It has not been conclusively demonstrated that such removal of overburden has resulted in sufficient relief of internal pressure to produce sheeting, although the well-developed flat-lying structural planes in the metamorphic rocks of low inclination give credence to this possible cause. The causes of sheeting in the granites of Georgia are therefore undetermined.

SHEETING IN RELATION TO THE OCCURRENCE OF GROUND WATER.

Occurrence of Ground Water.—Cascades of water emerge during heavy rainstorms from planes of sheeting that crop out on the steep northwestern slope of Stone Mountain. Although Stone Mountain is a striking feature and might be considered exceptional, the geologic processes operative in the area of the dome are commonplace. The well-developed sheeting there has contributed much to the conclusions here derived.

The constituent grains of crystalline rocks are so closely interlocked that the porosity is small. Joints and other fractures, therefore, offer the only media for circulation of water in these rocks. The gneisses and schists forming the normal metamorphic equivalents of granites display some degree of fracturing parallel with the schistosity, at some angle with it, or forming a network of both. If openings resulting from sheeting are excluded, granite, in the strictest sense, generally shows only limited fracturing. Ellis [8] recognized two sets of joints, vertical and horizontal, in the granites of Connecticut. He stated that the horizontal joints (possibly representing sheeted planes) were of subordinate importance in the occurrence of ground water. This is in contrast to the granites of Georgia, where sheeting yields the most important and the only systematic parting planes. Cross joints intersect and join sheeting planes at various angles, but their occurrence is decidedly sporadic, and they are limited in length and width. Many of these short cross joints owe their origin to the breaking of imperfectly sheeted bodies.

Part of the rain water seeps into the ground and percolates downward through soil and decomposed granite until the less altered rock is reached, at which level the water is usually diverted laterally along the slope of the hard rock. Sporadic fractures and other openings in the sheeted zones then allow this subsurface water to percolate downward again until it is shunted along the rock slope, or sheeted plane, below. In this manner subsurface water moves steplike downward along sheeted planes and non-horizontal fractures until the zone of saturation is reached. Valleys, in which there is pseudosynclinal sheeting, form ground-water basins which are normally the receptacles for ground water (Fig. 1).

[8] Ellis, E. E., A study of the occurrence of water in crystalline rocks, in underground water resources of Connecticut: U. S. Geol. Survey Water-Supply Paper 232, pp. 61–64, 1909.

Yields of Wells.—Greater quantities of ground water should therefore be found in granitic lowlands than in uplands. As representative of yields from areas of contrasting topography the following examples are cited:

The town of Sparta, in Hancock County, obtains its municipal water supply from a series of wells in an extensive body of coarse-grained granite. Many exposures of fresh granite occur in this area and all artificial excavations examined show distinct sheeting. One well, 462 feet in depth, located on a hill top, yielded only 2 gallons a minute on pumping test and has been abandoned. Three shallower wells situated at successively lower elevations yield 30, 39, and 75 gallons a minute, respectively.

Another example is found at Milstead, Rockdale County, where granite of the type occurring at Lithonia forms the country rock over a considerable area. Of two comparable wells located on contrasting topographic sites, the well in the lowland yields 60 gallons per minute and that on the upland only about 20.

At Ben Hill, Fulton County, in another area of granite of considerable extent, two wells were recently drilled on contrasting topographic sites. The first well, on the upland, reached a depth of 500 feet without producing any appreciable quantity of water. The second well, only a relatively short distance away but in a lowland, yielded 144 gallons per minute at a depth of only 95 feet.

The examples cited indicate that greater yields may be obtained from wells in lowlands than from those on uplands, yet the practice of locating wells in lowlands is not generally followed in Georgia. Most wells are drilled on hills and uplands for the sake of convenience and because wells in lowlands may be relatively difficult to protect from pollution. As a result of this practice, many wells located on hills have failed to yield the required, or desired, quantity of water. Further, this has resulted in the general but erroneous opinion that granite is the poorest producer of ground water. No drilled well located in a topographically low part of a mass of granite is known that can be classed as a complete failure.

The average yields from wells drilled in the granites of Connecticut [9] are reported to be about 13 gallons per minute. The yield in northern Virginia is reportedly about 8 gallons per minute.[10] Mundorff [11] reports the average for wells in similar terranes of North Carolina as slightly in excess of 10 gallons per minute. If such an average were compiled for Georgia, figures approximating those cited would likely result. Whereas these averages are true for existing wells, they are misleading as applied to the potential average yield, at least for granitic areas in Georgia. The average yield in Georgia, including equal numbers of wells on uplands and lowlands, should easily exceed 25 gallons per minute.

[9] Ellis, E. E., A study of the occurrence of water in crystalline rocks, in underground water resources of Connecticut: U. S. Geol. Survey Water-Supply Paper 232, pp. 101–102, 1909.

[10] Cady, R. C., Ground-water resources of northern Virginia: Virginia Geol. Survey Bull. 50, pp. 42–43, 1938.

[11] Mundorff, M. J., Ground water in the Halifax area, North Carolina: North Carolina Dept. Cons. and Devel., Div. Min. Resources Bull. 51, p. 22, 1946.

Artesian Conditions.—Artesian conditions are extremely rare in igneous and metamorphic rocks. Under ideal conditons artesian pressure may be built up in lowland sheeted openings. Where intersheet zones are rather continuous and are crossed by few fractures, they act as confining beds for ground water moving under hydrostatic pressure down the sheeted planes (Fig. 1). High-pressure flowing wells can hardly be realized under such conditions because sheeting produces relatively short and shallow water-bearing channels, and fractures crossing the sheeted planes allow enough leakage to reduce the pressure. At Sockwell's Mill, 3 miles south of Lithonia, DeKalb County, a well drilled 400 feet into fresh granite had a natural flow, the artesian head being approximately 2 feet above the ground surface. The prevalence of sheet structure and absence of any distinct cross fracturing suggest that sheeting is responsible for the structure that produces the artesian pressure in this well.

Springs.—Springs arising from granites are fairly common in Georgia, although their utilization has not yet been fully realized. Such water represents leakage of ground water from sheeted upland areas.

Seepage occurs along moisture-laden sheeted planes that crop out, usually where the surface slope is steep. Artificial excavations, such as quarries and road cuts, in places truncate water-filled sheet openings, allowing seepage. A series of road cuts on State Highway 37, 3 miles south of Franklin, in Heard County, show seepage from truncated sheet openings in fresh granite. Such leakage, where concentrated rather than diffused, might properly be termed a "sheet spring" (Figs. 1, 3). Because sheeted openings are generally narrow and the movement of water is slow, there is little chance for springs of large yield to be formed in this manner. Inasmuch as most of these springs emerge above the regional water table, their yields will likely be intermittent. Larger springs issue at the contact of the surficial weathered material and the uppermost hard granite sheet in some lowland areas. Although these are not true sheet springs, they are controlled, in part, by the convexity of the sheeted planes in upland areas from which the water is derived. All the granites yield, through weathering, round-topped hills whose curvature differs from place to place but is generally greater than that of the sheeted planes. Between the convex upland slopes and the concave valley is an intervening tangent slope which truncates some shallow convex sheet openings carrying water. Along these tangent slopes are almost all the springs arising from the granites.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
Oct. 2, 1948.

A METHOD FOR POLISHING SECTIONS OF ORES.

EDWARD SAMPSON.

ABSTRACT.

The procedure starts with rough ground specimen. Grinding is in two stages on iron laps designed to maintain a flat surface as the lap wears. Polishing is done on a lead lap. The construction and operation of the machines are described and grades of abrasives and special mixtures of oils are given. Grinding and polishing can be done with specimen held in the hand. A supplementary device holding a mounted specimen mechanically permits high pressure for polishing and greatly reduces polishing time for hard materials. The grinding methods are effective in making thin sections.

GENERAL STATEMENT.

THE equipment and methods herein described have been found effective in producing a flat-polished section of ore minerals. The equipment is simple, the method relatively fast, and a high degree of skill and training is not required to produce sections of good quality. The equipment here described assumes the availability of other equipment for cutting and rough grinding.

The process is carried out in three stages, two of grinding on iron laps and one of polishing on a lead lap. The new features of the process are the design of iron laps which will maintain a satisfactorily flat surface and the use of a mixture of oils to give a proper "bite" to the abrasive. Grinding and polishing are done by hand with either mounted or unmounted specimens; however an accessory device for holding a mounted specimen during polishing and permitting heavy pressure greatly hastens the polishing of hard minerals.

The following description is intended to be adequate to permit any one with machine shop facilities to construct the equipment. Arrangements have been made with S. G. Frantz Co., 161 Grand Street, New York, N. Y., to manufacture the equipment.

ACKNOWLEDGMENTS.

In working out the methods and equipment finally adopted, use has been made of the experience of many people. The pioneering work of polishing with metal laps was carried out by Vanderwilt [1] and embodied in the now widely used Graton-Vanderwilt polishing machine. The late Philip Krieger called the writer's attention to the abrasives of the American Optical Co. which he had used most effectively. I am particularly indebted to William H. Patmore, Research Assistant to the writer, who devoted much time and exercised keen ingenuity in experimenting with a large number of liquids to determine satisfactory mixtures. He also is largely responsible for the development of the mechanical equipment. The machines now in use were made by Ralph

[1] Vanderwilt, J. W., Improvements in polishing ores: ECON. GEOL., vol. 23, pp. 292–316, 1928.

Osborn, Superintendent of the machine shop of the Physics Department of Princeton University, who also worked out detailed problems of design. Jorma O. Kalliokoski, Research Assistant to the writer, suggested the use of high pressure in the final polish.

DRIVING EQUIPMENT.

Figures 1 and 2 illustrate the nature and arrangement of the equipment.* Any other drive to give the proper speed of rotation will serve, but the arrangement illustrated has proved satisfactory after considerable use. The bearings of the vertical shaft have been particularly satisfactory. Both lower and upper bearings are conical and the height of the lower thrust bearing is adjustable so that wear may be compensated. The lower bearing is a 60° cone of brass and the upper bearing is a brass cone with a slope of 4 inches per foot. As shaft and bearings wear to each other the fit remains good. Any type of reduction pulley to give proper operating speeds is satisfactory, the one illustrated in Figure 1 being made of equipment which was at hand. The lead lap, which has the highest speed of rotation, does not require an intermediate pulley for speed reduction and if the three laps are mounted in a single line the two iron-lap units can be driven through the lead-lap unit, thus eliminating speed-reduction pulleys. If the expense of an additional motor is not a controlling factor it is desirable to mount the lead lap on a separate table as shown in Figure 8.

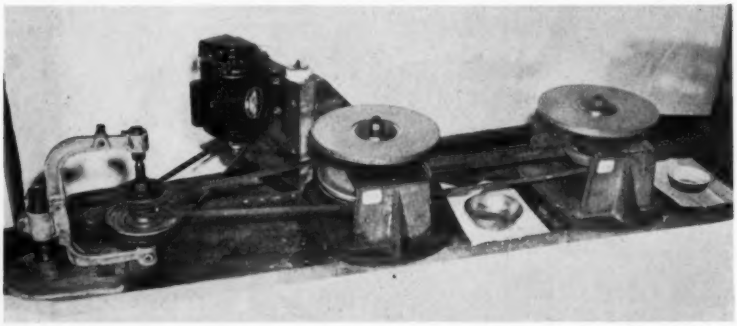

FIG. 1. General view of grinding laps.

Laps.—Much difficulty in making polished sections on metal laps has been caused by iron grinding laps which wore to a concave surface producing a crowned surface on the specimen. This crowned surface made polishing difficult or excessively slow. The laps used have an annular grinding surface and

* It has not been possible to reproduce the working drawings but the writer has a moderate number of copies which will be sent to those interested.

The equipment made by the S. G. Frantz Co. has the motor and driving mechanism mounted below a steel-topped table, two iron laps and one lead lap being mounted on one table.

the specimen moves over the whole grinding surface of the lap including the inner and outer edges. Grooves about 1/32 inch wide and somewhat less deep were cut into the surface of the lap to equalize wear by removing metal from the parts least subject to wear. The spacing of the grooves is shown in Figure 3, the spacing selected being inversely proportional to the wear on an old lap.

Figure 3 shows profiles of the iron laps after two years of wear. The profiles are of one side of the annular grinding surface. The amount of relief shown by these profiles causes no trouble in the polishing stage.

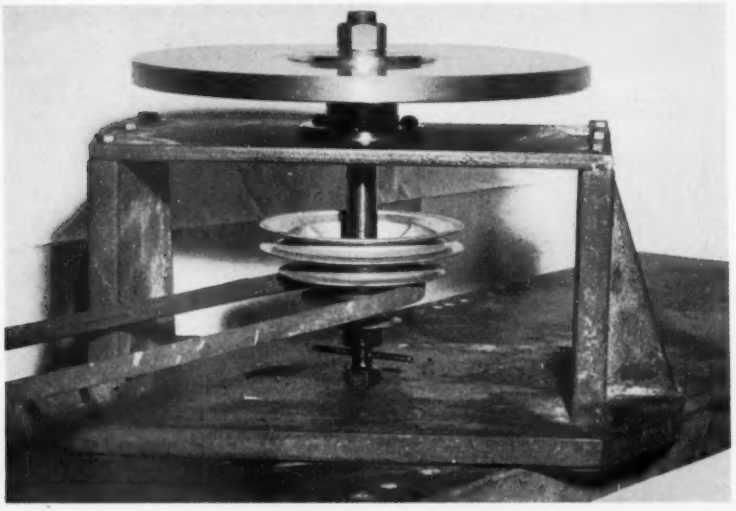

FIG. 2. Close-up view of lap and driving mechanism. The frame has been turned on the table for better visibility.

The laps used for grinding are made of gray cast iron. They were originally finished by grinding them against each other, three laps being alternated. This resulted in an optically flat surface. However, present standards of a very smooth lathe cut give a satisfactory surface if it is worked down with a flat block of agate. It is desirable to round the edges of the grooves with a small abrasive wheel to eliminate any ragged pieces of metal.

The lead lap was originally made for the Graton-Vanderwilt polishing machine by the Mann Instrument Co.[2] This lap is made by casting about 1/8 inch of lead onto an iron plate containing 32 1/2-inch holes. The original lap was modified by machining to give an annular polishing surface and works best without grooves.

[2] 80 Trowbridge Street, Cambridge, Mass.

OPERATION.

Preparation.—The specimen is prepared by normal grinding with 3F carborundum. If a saw cut is very smooth this may be unnecessary. It is of great importance that the edges of the specimen or bakelite mount be very carefully beveled to prevent planing the surface of the lead lap during final polishing. The bevel is put on with a curve so that it comes in nearly tangent to the face of the specimen. In beveling the specimen it is best to put on a rough bevel in the preparation stage and then, after the grinding with 305 abrasive, to put on the final level.[3]

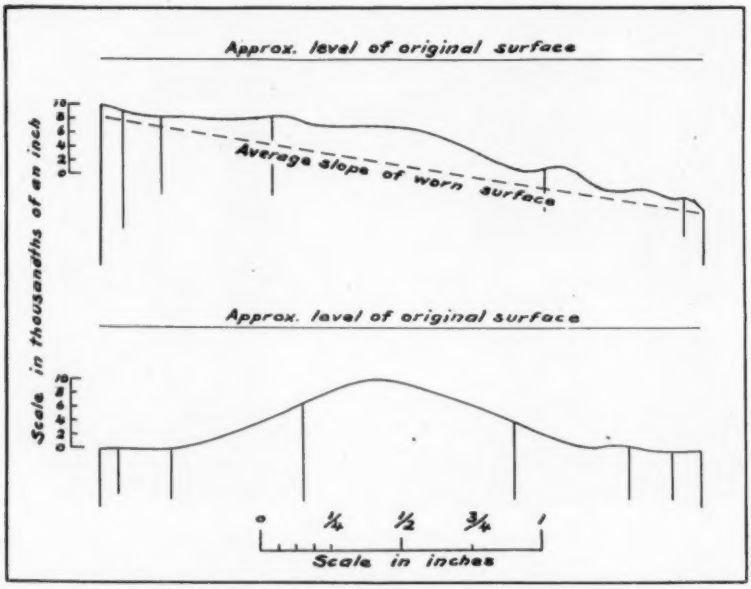

FIG. 3. Profiles of iron lap surfaces after two years wear. The upper profile is the lap using 303½ abrasive and the lower profile that using 305 abrasive. The left hand side is the outer edge of the lap.

First-Stage Grinding.—The first stage of grinding is done with 303½ abrasive of the American Optical Co.[4] mixed with oil to give a consistency of milk. The oil is a mixture of 8 cc kerosene, 3 cc mineral oil and 10 drops of lard oil. The lard oil has a marked effect in producing the proper bite of the abrasive. The abrasive-oil mixture is applied with the fingers and dis-

[3] For the final bevel a solid grinding wheel of fine abrasive in a plastic bond is satisfactory. The grinding is done with water applied to the wheel.

[4] American Optical Co., 155 East 44th Street, New York City. The price of abrasives, grades 303½ and 305, is about $1.00 per pound.

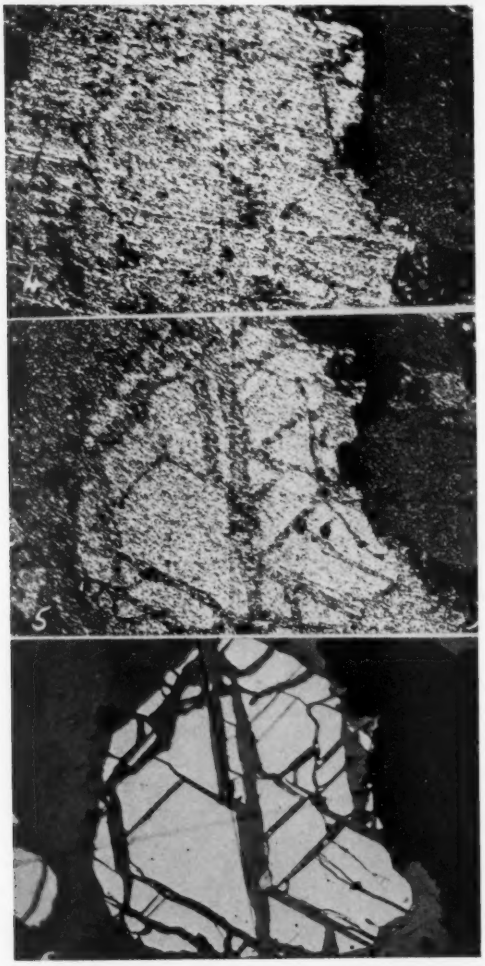

FIG. 4 (top). Section showing surface after first stage grinding with abrasive No. 303½. Same area as in Figure 6. × 158.

FIG. 5 (middle). Section showing surface after second stage grinding with abrasive No. 305. Same area as in Figure 6. × 158.

FIG. 6 (lower). Section showing final polish on lead lap. Same area as Figures 4 and 5. White, pyrite; dark gray, bornite; light gray, chalcopyrite; black, pit. Specimen from Butte, Montana. × 158.

tributed so that the rotating lap has an oily feel, with no pull to the fingers. The amount applied should not be so much as to cause liquid to fly from the lap. During grinding it is important that the specimen be held always in the same position without rotation; otherwise two surfaces may develop and it will probably be necessary to go back to coarse grinding to restore a single surface. To induce even wear on the lap, the specimen is moved back and forth across the lap with a uniform motion and is carried so that it slightly overlaps both the inner and outer edges of the annular grinding surface. A very light pressure is applied, barely the weight of the hands. A lap speed of 120 RPM has been found to be satisfactory.

After about a minute of grinding so much material is removed from the specimen that it is necessary to clean the lap by wiping with cleansing tissue. A fresh supply of abrasive in oil is then added. Two minutes of first-stage grinding is commonly sufficient. The specimen is then washed with dry-cleaning fluid [5] applied with a toothbrush. Separate jars of fluid are used for cleaning the specimens from each lap. The nature of the surface produced by the first-stage of grinding is shown in Figure 4.

Second-Stage Grinding.—For the second stage, a lap is used identical with that of the first stage, but with a speed of about 165 RPM. Grade 305 Abrasive (American Optical Co.) is mixed to a milky consistency with oil composed of 9 cc kerosene, 2 cc mineral oil and 4 drops of lard oil. The procedure is the same as for the first stage. Ordinarily 2 to 3 minutes of grinding is adequate, and the lap is wiped clean as soon as it gets dry or sticky, which is usually about every one or two minutes. It is of utmost importance to carry this stage of grinding to its limit for if it is not carried to its limit, polishing time will be greatly increased. At the end of this stage the minerals of the specimen should have an even matte surface, free from scratches, as illustrated by Figure 5.

When the laps are not in use they should be left with a moderate amount of the polishing oil (and debris) on the surface to prevent rusting. Before use, the lap is carefully cleaned with cleansing tissue dipped in cleaning fluid.

Polishing.—Polishing is done on a lead lap rotating about 350 RPM. The abrasive is the purest magnesium oxide available.[6] The oil used consists of 2 cc kerosene, 4 cc mineral oil, 2 drops lard oil. For some very soft minerals it has been found that 2 drops of Jergen's lotion, in place of lard oil, gives better results. The consistency of the mixture is critical. A small quantity of magnesia is placed in a dish and then the oil mixture added with a dropper. This usually results in a slight excess of oil and the consistency is made correct by adding more powder. The final mix has a nearly dry feel which cannot be accurately described. A mixture in the proportion of 1.4 g of magnesia and 1.0 g. of oil has been satisfactory although this may vary slightly with different batches of magnesia. The abrasive paste is rubbed onto the lead lap, using the least possible amount to cover the lead. This is well distributed

[5] The cheapest kind of dry-cleaning fluid carried by chain drug stores for about 80 cents a gallon is satisfactory.

[6] It is desirable to obtain this directly from the maker and to specify that a fresh lot ("sulfate free") be sent. The oxide turns to carbonate on exposure to air. It is desirable to transfer a new batch of powder to glass tubes. These are corked and sealed with paraffin.

with the flat of two fingers or occasionally is further worked into the lap with a steel block while the lap rotates. The block has a high polish and by the nature of the smear on its surface the state of the abrasive on the lap can be gauged. If there is no smear on the block the lap is too dry. A heavy coating indicates too much paste and probably also too wet a paste. The proper application of paste causes the smear on the block to be in broad bands.

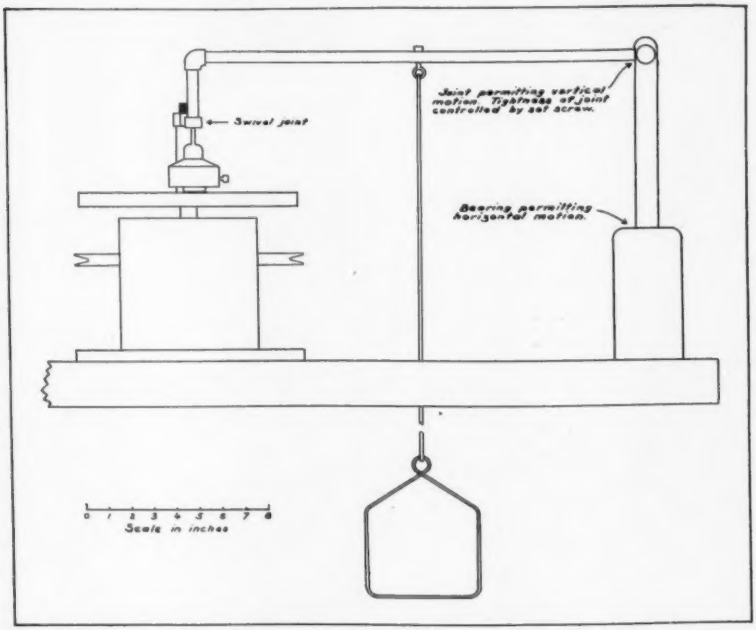
Swivel joint
Joint permitting vertical motion. Tightness of joint controlled by set screw.
Bearing permitting horizontal motion.
0 1 2 3 4 5 6 7 8
Scale in inches

FIG. 7. Device for holding mounted specimen and for applying heavy pressure.

The lap is cleaned by applying a strong solution of lye to the surface. After soaking for some minutes, scrubbing the surface with a nail brush removes much debris. If the lap surface has been damaged, considerable improvement can be made by applying a hot flat-iron while running the lap on one of the iron lap spindles (for lower speed).

Polishing is done with heavy pressure. With an ordinary specimen held by the fingers a pressure of from 20 to 30 pounds may be applied. A supplementary device has been found useful whereby the mounted specimen is held in a clamp from a movable arm above the lap. A wire and stirrup are attached to this arm and pressure is applied by the foot. Figures 7 and 8 show the arrangement of the equipment. This device greatly lessens the time of polishing hard minerals. It has been found that magnetite specimens, which

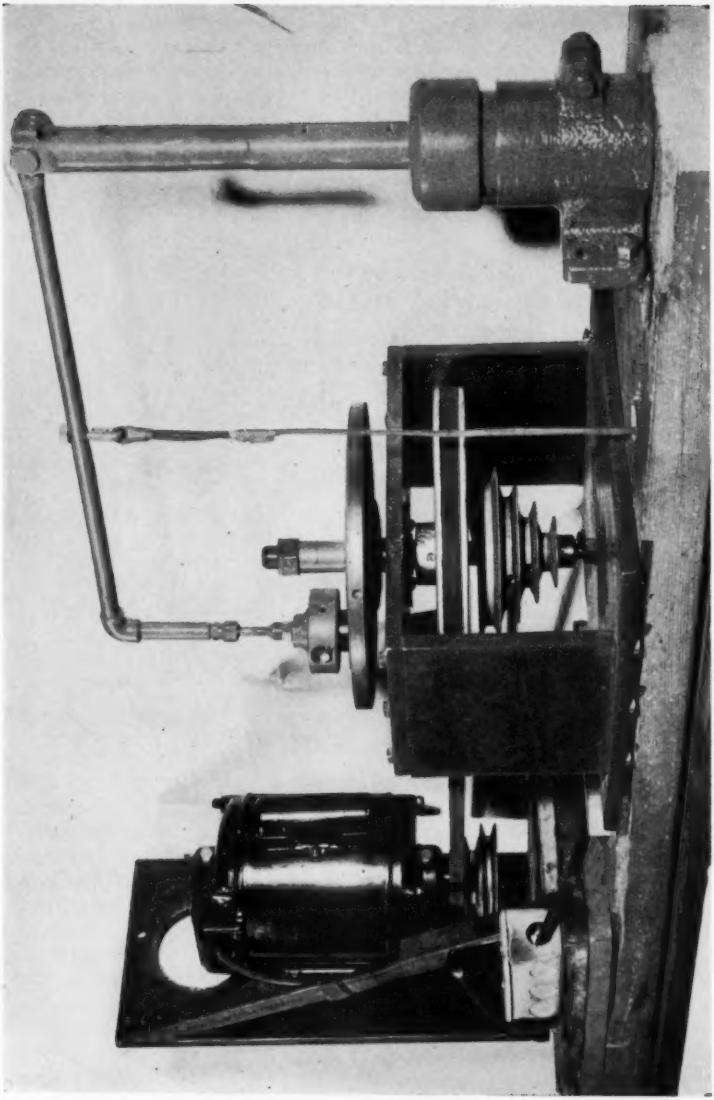

FIG. 8. Polishing lap showing device for holding mounted specimen. Heavy pressure is applied by the operator's foot at a stirrup at the end of cable seen running through table.

are difficult to polish, can be polished in from 2 to 3 minutes as compared to equivalent results of nearly 10 minutes polishing time by hand. In using this device the specimen must be firmly held and care taken not to apply foot pressure until the specimen surface is in perfect contact with the lap. Lack of care may result in the specimen chattering on the lap surface.[7]

THIN SECTIONS.

It has been found that the grinding equipment is also useful for making thin sections. Some advantages over ordinary methods are as follows. The usual procedure of making thin sections (unless crowned laps are used) commonly results in the surface which is to be cemented to the glass having a crowned surface with the result that when the second surface is ground the edges are thinner than the center. The present method of grinding yields a flat surface for cementing to the glass slide. Furthermore this surface has much less than ordinary relief and deep cracks are minimized as is shown in Figure 5.

Grinding during the final stage is under close control and a high degree of skill is not necessary in making a good section of standard thickness.

For making a thin section an additional iron lap is used with 600 carborundum and the same oil mixture as with abrasive No. 303½. Before mounting the specimen the surface is finished with 303½ or 305 abrasive. Sections must be mounted with glycol phthalate,[8] and balsam cannot be used because of reaction with the oil. (The index of glycol phthalate is Na 1.670.) After mounting the slide, rough grinding is carried out as usual until the section is a few tenths of a millimeter thick. With firm rocks the 600 carborundum will produce a finished section but if difficulty is encountered use of the 303½ abrasive reduces the speed of cutting and permits close control for extremely difficult sections. The 305 abrasive permits closer control. An ordinary rock can be ground from a thickness yielding second order blues with quartz or feldspar to a finished section in about two minutes grinding time.

DEPARTMENT OF GEOLOGY,
PRINCETON UNIVERSITY,
June 17, 1948.

[7] Since this paper was in proof the S. G. Frantz Co. has constructed a three-lap polishing machine. On this machine the arrangement for holding the mounted specimen over the lead lap is much improved over that shown in Figures 7 and 8. Instead of a free moving joint above the specimen, the vertical rod has a conical end which fits into a conical hole in the top of the specimen holder; which hole has a cone 2° greater in opening than the one on the rod. This permits slight movement so that the specimen can conform to the lap surface, but prevents the specimen turning over and gouging the lap surface.

[8] This material can be secured from the General Electric Co., Schenectady, New York, for about $1.50 per pound.

PAIKUNGSHAN COAL FIELD—A NEW DISCOVERY IN THE HUAINAN BASIN, NORTHERN ANHUI, CENTRAL CHINA.

C. Y. HSIEH.

ABSTRACT.

A new coal deposit in the Huainan Basin, Northern Anhui Province, China, has proved to be an important discovery as well as a successful achievement for the geologists of the Mineral Exploration Bureau of the Mineral Resources Commission of China.

Called the Paikungshan, this field lies under the alluvial flats of the Huai Ho River and is part of a structural basin (Huainan) bounded by mountain ranges. The structure of this basin is complex. The Shenkengshan coal field to the south is in overturned beds which have long complicated the structural interpretation of the district. The coal is of middle and upper Permian age.

Using the underlying Ordovician beds as markers, it was possible to extrapolate the sedimentary series from the known Shenkengshan deposits into the new prospecting area, and a subsequent core drilling campaign was successful in locating commercial coal measures in the fall of 1946. To date 27 seams have been located which have an aggregate thickness of 39 meters. Known reserves total over 600 million tons, all of which lie within 600 meters of the surface.

Incidental to the coal prospecting, other potentially important finds include phosphate rock, siderite, diaspore, clay, glass sand, and oil shale.

Of considerable commercial importance regarding this new coal discovery is the fact that the measure contains two seams which are suitable for making a high-grade metallurgical coke.

INTRODUCTION.

In a large country like China, with mineral resources not fully developed and geology only partially known the chance of finding new mineral deposits is great. Special opportunity is afforded by coal, which, because of its more or less uniform and extensive mode of occurrence, is one of the best objectives for geological exploration. Since the outset of the Chinese Republic, there have been many instances of coal finds by Chinese geologists; the most important and successful of these has been the discovery of the new coal field in the Huainan basin of northern Anhui, central China.

The coal beds in the Huainan basin (Fig. 1) have been exploited on a modern scale for many years. Formerly, there were two concessions—a central tract, worked by the Tatung Coal Mining Company, and western and eastern areas under the management of the Huainan Coal Mining Administration. The Tatung Company had the best property and was producing some 1,800 tons of coal per day prior to the Sino-Japanese war. The Huainan Administration's lands were in the less attractive parts of the district, but they had shipping advantages, having built and operated a 220-kilometer railroad joining the mine and Yuchikou, a port on the Yangtze River near Wuhu.

During the war, the field was occupied by Japanese. They added some surface structures and constructed 85 km of railroad from the district of Pengpu, a commercial center on the Tientsin-Pukow Railroad. Some geological surveying, seismic investigations and diamond core drilling were also conducted in this period. Despite all of these efforts, the Japanese operators unearthed no new deposits of value and failed to effect much improvement in engineering and management. As the underground openings were not properly maintained, great difficulty was encountered in rehabilitation after the Japanese occupation.

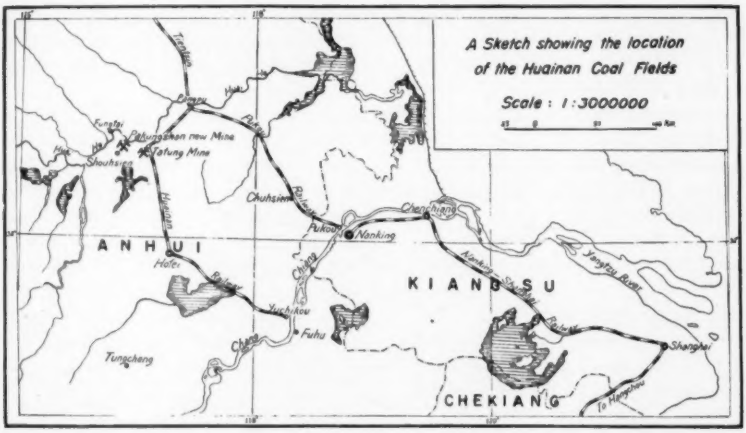

FIG. 1.

Since V-J Day, all the mines in the field have been amalgamated and are now under the directorship of the Huainan Mining and Railway Company, financed by both government funds and private capital. With good supervision and sound engineering, mining operations have been resumed, and at present the daily output of coal is approximately 4,000 tons.

Paikungshan, the newly discovered field, is contained in an irregularly shaped concession about eight km long by three or more km wide. The concession lies on the alluvial flats of the Huai Ho River northeast of the Paikunkshan range of mountains with its long dimension parallel to this range. The Shenkengshan coal field, in the older part of the district, is some 15 km to the southeast, and is along the north side of the Shenkengshan Mountains. To the north and west there is the small isolated Minlungshan Mountain, and on the east side of the district, there are the mountains of Shangyao and Wutien. Thus, the Huai Ho River flats in this area form a wide basin which is bounded almost on all sides by mountains. This large feature is known as the "Huainan basin."

GEOMORPHOLOGY AND STRUCTURE OF THE HUAINAN BASIN.

The border mountains of the basin are composed of a thick sequence of sedimentary rocks, ranging in age from Sinian to Permo-Carboniferous. Bedrock in the basin itself is concealed by a thick mantle of alluvium, but based on structural premises, as well as on drilling and seismic data, it may be stated that the alluvium is directly underlain by formations of post-Sinian age. The Paikungshan and Shuenkengshan coal fields are on the southern limb of this large Huainan synclinorium. Scattered outcrops of hornblende and mica schist correlative with the Wutai formation of Precambrian age are found on the south side of the Paikungshan-Shenkengshan mountains, and the alluvium-covered plains, lying to the south of these mountains, are also doubtlessly underlain by this formation. The schist has been deeply denuded. It marks, however, the site of the old Tsingling chain which has been a land barrier since Sinian time.

The mountains on the edge of the basin were formed by forces acting in north and south directions. The overturned position of the coal measures at Shuenkengshan clearly indicates a northward stress, whereas the great thrust faults in the Fungtai-Shouhsien area on the south are the result of southward compression. A southward compression also seems to have been the dominant force acting on the north limb of the synclinorium at Minglungshan and Shangyao. Further evidence of a southward force is indicated by south-pointing apex of the arcuate pattern formed by the Paikungshan and Shenkengshan ranges. Thus, it may be concluded that the dominant stress was toward the south and that the overturned structure at Shuenkengshan is the result of the reactionary northward stress produced by the resistant mass of the old Tsingling chain.

COAL IN THE SHENKENGSHAN-SHANGYAO SECTOR OF THE HUAINAN BASIN.

In the Shenkengshan field, the mines are working a Permian coal measure beneath the alluvial plain north of the Shenkengshan range. More than twenty seams, with an aggregate thickness of 26.7 m, are found in the measure. Eight to fourteen of these, ranging in thickness from 1 to 5 m, are workable. They contain bituminous coal high in volatiles, low in sulfur, and with a medium ash content. With the exception of one seam, discovered during the present study, the coal does not possess good coking properties.

Detailed stratigraphic studies in the Shenkengshan field show that the coal measure, as well as the overlying and underlying formations, is overturned to the north and that the entire sequence has a steep inclination (60° to 85°) to the south. This overturned and steep attitude has contributed

FIG. 2. *Q*, Quaternary and Recent; gravel and alluvium. *T*, Triassic; red sandstone and shale. *P*, Permian; coal series. *Cp*, Permo-carboniferous, fusulina limestone. *O*, Ordovician; limestone and shale. *C*, Cambrian; oolitic limestone, shale, crystalline limestone, Shengkengshan sandstone, limestone and purple shale, purple limestone breccia and shaly limestone with a bed of phosphate rock. *H*, Sinian; siliceous limestone with collenia, quartzite, green shale and thin-bedded limestone. *W*, Wutai; hornblende and mica schists.

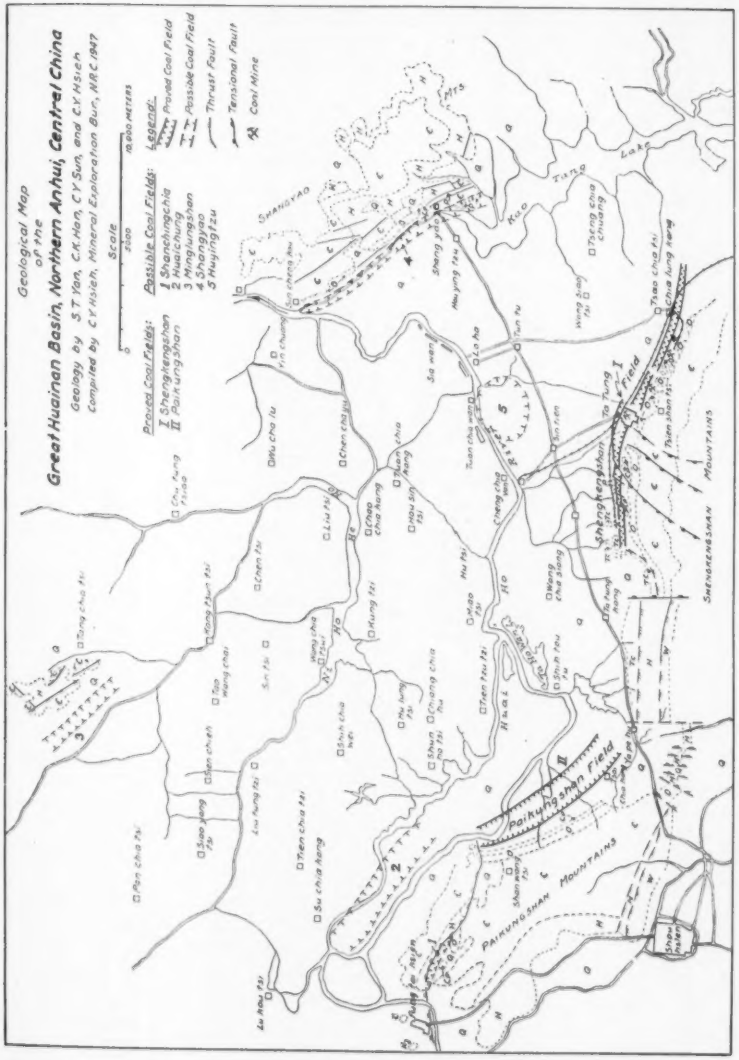
Geological Map
of the
Great Huainan Basin, Northern Anhui, Central China
Geology by S.T. Yen, C.K. Han, C.Y. Sun, and C.Y. Hsieh
Compiled by C.Y. Hsieh, Mineral Exploration Bur., NRC, 1947
Scale
Legend:
Proved Coal Fields:
I Shengtengshan
II Paikungshan
Possible Coal Fields:
1 Shanchungcha
2 Huaichung
3 Minglungshan
4 Shangyao
5 Huajing'zu
Proved Coal Field
Possible Coal Field
Thrust Fault
Tensional Fault
Coal Mine
Paikungshan Field
Shengtengshan Field
Paikungshan Mountains
Shengtengshan Mountains

FIG. 2.

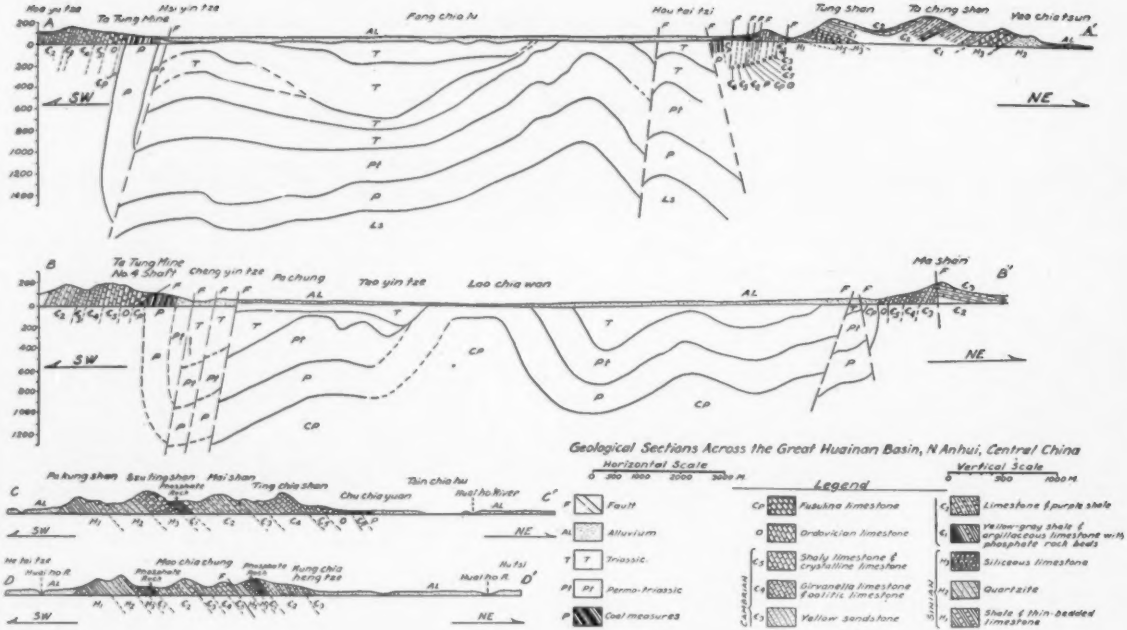
Hou yu tsz
Ta Tung Mine
Hsi yin tsz
Fang chia hu
Hou tai tsz
Tung shan
To ching shan
Yao chia tsun
SW
NE
Ta Tung Mine No. 4 Shaft
Cheng yin tsz
Pa chung
Tao yin tsz
Lao chia wan
Ma Shan
Pa kung shan
Szu ting shan
Mei shan
Ting chia shan
Chu chia yuan
Tsin chia hu
Huai ho River
He tai tsz
Huai ho R.
Miao chia chung
Kung chia heng tsz
Hu tsi
Geological Sections Across the Great Huainan Basin, N Anhui, Central China
Horizontal Scale
Vertical Scale
Legend
Fault
Alluvium
Triassic.
Permo-Triassic
Coal measures
Fusulina limestone
Ordovician limestone
Shaly limestone & crystalline limestone
Girvanella limestone & oolitic limestone
Yellow sandstone
Limestone & purple shale
Yellow-gray shale & argillaceous limestone with phosphate rock beds
Siliceous limestone
Quartzite
Shale & thin-bedded limestone
CAMBRIAN
SINIAN

FIG. 3.

greatly to mining difficulties. Coals above the 180-meter level are practically depleted. Workings now extend to a depth of 330 m; mining at greater depths would require deepening of the shafts. Equipment, however, is inadequate for deeper work, and, therefore, the relatively shallow, flat seams, discovered in the Paikungshan field, have added greatly to the economic importance of the basin.

Coal in the Shangyao field, which lies about 15 km northeast of the Shenkengshan mines, has been known and used by local people for many years. Because the strata dip southwest, or are overturned to the northeast, at Shangyao, it has long been conjectured that they and the formations exposed at Shenkengshan are on the opposite limbs of a large synclinal structure and that coal exists at considerable depth beneath the intervening alluvial plain. A seismic survey, conducted by the Japanese to prove this structure, indicated the possible existence of the coal measure at depths from 500 to 1,000 m. From these geological and geophysical data, then, this part of the Huainan basin appears to be a fan-shaped synclinorium with several anticlines and domes in the middle of the structure and with mountains and faults on either flank (Fig. 3). Along the axes of the anticlines, coal may lie at a depth of about 500 m. However, two holes, drilled by the Japanese, were abandoned at depths of 182 and 264 m after failing to find coal at points where the seismograph suggested its presence at 100 m, or less.

In April, 1946, the author was invited by the authorities of the Huainan Mining and Railway Company to discuss the possibilities of exploring for concealed coal in the basin between Shenkengshan and Shangyao. But, as pointed out in the aforegoing, coal in this area is known to occur only at great depth. A proposal was made and accepted, therefore, to investigate in the vicinity of Shenkengshan for new, shallow deposits. The Nanking-Kaifeng sheet, published by the Central Geological Survey of China, shows a strip of Ordovician limestone on the slopes of the Paikungshan Mountain dipping northeast toward the central part of the basin, As the Ordovician limestone is at the base of the coal measure, it was decided to study further the potentialities of the tract northeast of this mountain. During a reconnaissance, the presence of the Ordovician limestone was verified, and another overlying limestone formation was found. This limestone has abundant fusulina, crinoid stems and brachiopoda and is doubtlessly correlative with the Uralian limestone, which, according to measured sections in the Huainan mine, is stratigraphically only 35 m below the lowest coal seam. The Uralian limestone crops out more or less continuously for a distance of more than six km on the plain northeast of the Paikungshan mountain. It dips northeast under the central plain of the Huainan basin at an angle of less than 30 degrees. Exposures of bedrock on the plain itself are unknown. Inasmuch as there is no evidence of a fault along this entire length of strike that would cause an undue amount of downward dislocation of the coal measure, it was decided that the area merited further attention. Accordingly, the natural exposures were mapped in greater detail, and in September of 1946 a systematic core drilling program was inaugurated. Within a week following the commencement of drilling, a coal seam 3.6 m thick was encountered beneath the

alluvium at a depth of 19 m, and subsequently, a total of 27 seams with an aggregate maximum thickness of 39.05 m were found. Drilling of the field is still in progress.

CORE DRILLING.

According to the plan, the whole field is to be explored by drilling nine series of holes—the series, each comprised of a line of holes at right angles to

FIG. 4.

the strike, are to be spaced at intervals of about 1 km or less (Fig. 4). The total thickness of the coal measure is about 500 m. The available drilling machines, however, are three of 200 m and one of 800 m capacity, and consequently, in order to section the entire coal measure, it is necessary to drill two or more holes along a line normal to the strike. Up to July, 1948, the first five series of drill holes have been successfully completed, and the other four series have been started. In addition to the principal holes, several auxiliary holes have been bored to ascertain the degree and direction of dip. Table I shows the number of holes completed and the coal seams encountered in each.

TABLE I.

Series	No. of principal holes	No. of seams	Total thickness of coal seams (meters)
A	6	24	38.90
B	2	17	29.61
C	2	20	30.50
D	3	27	39.05
E	2	17	19.30
F	1	9	17.80
G	1	2	0.90
H	1	9	17.10
I	1		
Total	19		

The drilling up to the end of June, 1948, totals 4,280.5 m, of which, 338.20 m were drilled in auxiliary holes. Among the 8–14 workable seams, there are four seams of more than three meters, four of between two and three meters, and several of between one and two meters in thickness. The explored length along the strike is now nearly eight kilometers and along the dip more than three kilometers. As the results from the different holes are in fairly good agreement, a total thickness of 25–30 m of workable seams can now be guaranteed. The total reserves of this newly discovered coal field should amount to more than 600 million tons, all lying within a maximum vertical depth of about 600 m.

CLOSE STUDY OF LOGS.

The cores from the drilling have been carefully preserved and closely studied. The section consists chiefly of sandstone, sandy shale and shale of gray, yellow and white colors. The sandstone is frequently arkosic and at certain horizons quartzitic. Associated with these common rocks, there are also some special materials, namely: siderite, diaspore clay, and purple shale. They are of importance, not only as key beds for correlation, but some of them, such as siderite and diaspore clay, have potential economic value. Thus far, five or seven strata of siderite, three zones of diaspore clay and purple shale (Fig. 5) are known. Diaspore clay and purple shale are usually closely associated, suggesting that climate may have been the dominant factor in their formation.

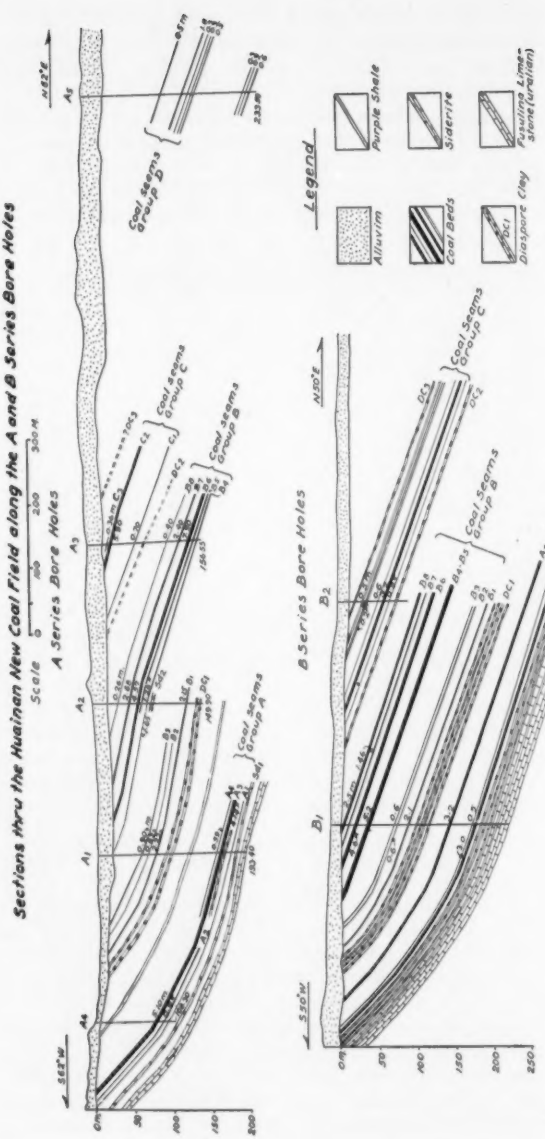
Sections thru the Huainan New Coal Field along the A and B Series Bore Holes
Scale
A Series Bore Holes
B Series Bore Holes
Legend
Alluvium
Coal Beds
Purple Shale
Siderite
Diaspore clay
Fossiliferous Limestone (oolitic)
Coal Seams Group A
Coal Seams Group B
Coal Seams Group C
Coal Seams Group D

FIG. 5.

The siderite is dark brown, dense, and heavy, with an iron content varying from 30 to 36 percent. It has a thickness from 0.4 to 1 m. It occurs usually in lenticular bodies and in large concretions of one-half to one meter, or more, in diameter and is often found in the shaly sediments near the coal seams. The diaspore clay is mostly gray, and displays a coarse concretionary structure. The microscope reveals that the concretions are made up in part by crystalline aggregates of diaspore; the matrix is a fine-grained material of amorphous character. In the lowest horizon of the clay, a light gray to white, fine-grained variety of diaspore, occasionally with oolitic texture, is associated with the coarse concretionary variety. Analyses of the diaspore clay are not available.

GROUPING OF THE COAL SEAMS.

From both the scientific and the practical point of view, a proper grouping of the coal seams is of the utmost importance. There are several ways to group, or correlate, the seams, but the one based on the persistent and particular kind of associated rocks, or key beds, is most reliable. In the Huainan coal field the diaspore clay and siderite are satisfactory for this purpose. As they are distinctive in lithological character, rather persistent in distribution, and are not too thick, they are ideal key beds. Whereas both diaspore clay and siderite are products of sedimentation in an open body of water, and coal is the accumulation of vegetal material in a swampy area, the repeated occurrence of these three items implies a fluctuating water level in the vast Huainan basin during the Permian period. The formation of diaspore clay suggests, furthermore, prolonged denudation and low relief, as well as a dry, hot climate. Coal, on the other hand, forms in cool climate. It is reasonable, therefore, that the grouping of the coal seams should be by means of these rocks which are the products of changing hydrographic and climatic environments. Another useful key bed is the white to light gray, coarse-grained, and commonly arkosic sandstone, which may attain in some place a thickness of more than 40 m. This sandstone represents a period of active erosion and deposition quite different from the conditions obtaining in the coal-forming epoch. It is also used, for this reason, as a marker to separate the different coal-bearing groups.

In general, the Huainan coal measure may be divided into four groups, each containing from four to as many as eight, or more, seams of coal. The bottom of each group is marked by a layer of diaspore clay (Figs. 5, 6). The lowest group, herein called the "A group," is equivalent to the No. 8, S. seam of the Shenkengshan field. This group, containing as many as four seams of coal, is directly above the Uralian limestone, and has two intercalated layers of siderite near its base. The diaspore clay horizon, separating the A and the B groups of coal, is especially distinctive, as it also has layers of purple shale and a zone of light gray to white, fine, dense material. Between the diaspore clay and the A group coals is a zone of white sandstone which is rather pure and coarse grained. The B group is the principal coal formation; it contains from six to ten seams of coal. Two or more layers of siderite are found in this group occurring usually in the shaly phases. A series of light

gray to whitish sandstone (30 to 40 m thick) separates the B and the C group, while between the C group coals and the sandstone, a layer of diaspore clay is again found. The C group, containing 3 to 7 seams of coal, has, however, only one to three seams that are thick enough to be workable. A total of three layers of siderite is found in the C group. Between the C and D groups, there is a thick layer of diaspore clay and shale with a coarse concretionary structure in places. The D group contains as many as ten seams of coal, only one of which has sufficient thickness (1.8 m) to be of commercial interest.

The above section applies not only to the rocks exposed in the nine series of bore holes already drilled in the new field, but it is also applicable to the

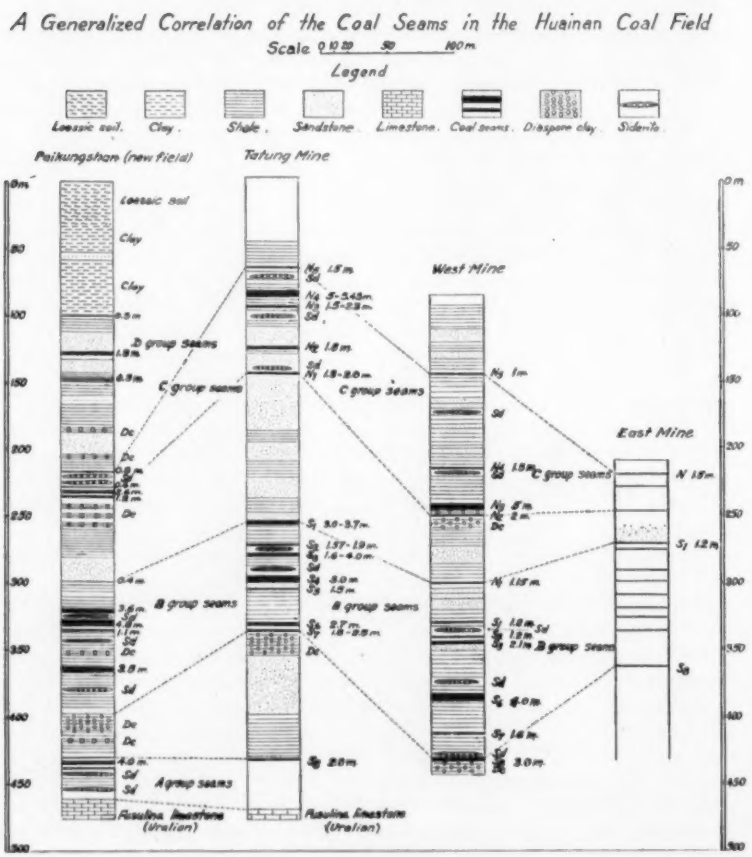
A Generalized Correlation of the Coal Seams in the Huainan Coal Field
Scale 0 10 20 50 100 m.
Legend
Loessic soil. Clay. Shale. Sandstone. Limestone. Coal seams. Diaspore clay. Siderite.
Paikungshan (new field)
Tatung Mine
West Mine
East Mine
D group seams
C group seams
B group seams
A group seams
Fusulina limestone (Uralian)

FIG. 6.

Tatung mine of the old field. In the western and the eastern mines of the old field, the succession, as well as the thickness of the different groups, is somewhat different than at Paikungshan, though the sections in the two fields are still roughly comparable. The southern seams (No. 1 to No. 7) of the old field are equivalent to the B group coals of the new field, whereas the northern seams of the old mine belong chiefly to the C group. The D groups coals have not yet been developed in the old field.

Table II shows the number of coal seams and their thickness in meters in the different groups as revealed thus far by the drilling:

TABLE II.

SERIES A (DRILL HOLES A1–A6).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
D	8	4.50	1	1.80
C	3	6.96	1	5.90
B	8–9	14.20–19.36	5	12.41–17.43
A	4	8.08	2	6.54
Total	23–24	33.74–38.90	9	26.65–31.67

SERIES B (DRILL HOLES B1 AND B2).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
C	7	5.85	1	3.20
B	7	17.06	5	15.86
A	3	6.70	2	6.20
Total	17	29.61	8	25.26

SERIES C (DRILL HOLES C1 AND C2).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
D	7	4.90	2	3.00
C	5	6.00	3	4.80
B	6	13.60	4	13.00
A	2	6.00	2	6.00
Total	20	30.50	11	26.80

SERIES D (DRILL HOLES D1–D3).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
D	10	11.80	5	9.20
C	6	8.70	2	6.70
B	10	16.15	6	12.85
A	1	2.40	1	2.40
Total	27	39.05	14	31.15

TABLE II.—*Continued*

SERIES E (DRILL HOLES E1 AND E2).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
D	3	0.90	—	—
C	4	7.20	1	6.20
B	7	6.90	3	4.30
A	3	4.30	1	3.80
Total	17	19.30	5	14.30

SERIES F (DRILL HOLE F1).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
C	—	—	—	—
B	6	12.50	4	12.10
A	3	5.30	2	4.80
Total	9	17.80	6	16.90

SERIES G (DRILL HOLE G1).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
B				
A	2	0.90	—	—
Total	2	0.90	—	—

SERIES H (DRILL HOLE H1).

Groups	No. of coal seams	Total thickness (m)	No. of workable seams	Thickness of workable seams (m)
B	5	12.60	5	12.60
A	4	4.50	2	3.30
Total	9	17.10	7	15.90

COKING COAL.

Chronologically speaking, the Huainan coal measure belongs partly to the Shansi series and partly to the Shihhotze series of middle and upper Permian, respectively. The A-group coal, lying immediately above the Uralian limestone, is a member of the Shansi series of middle Permian age, but the other seams from group B to group D contain *Gigantopteris* flora, and, therefore, are correlative with the Shihhotze or upper Permian.

It is well known that the principal coal measures of northern China belong either to Shansi series or to Uralian, whereas in southern China the main coal forming epoch was in the Gigantopteris era of upper Permian age. The

general geological succession of the Huainan coal field bears a close resemblance to the northern fields; yet the stratigraphic position of the coal seams is much higher as in the southern fields. This remarkable dual character, however, is not surprising since Huainan lies in a transitional position between north and south China.

On the basis of stratigraphy, the A group, or the No. 8, S. seams can be correlated with the "Tachao," or the great seams of the Chunghsing coal field in Southern Shantung. As the latter is the best coking coal in eastern central China, the question arose as to whether the A group or the No. 8 S. seams, of Huainan were not also good coking coals. Accordingly, the Huainan mine made a number of tests on the No. 8 S. seam coal and determined that it will yield good coke low in both sulfur and ash. The discovery that the No. 8 S. seam and most probably the A group coals are suitable for making a fair-grade metallurgical coke will increase immensely the industrial value of the Huainan field.

DEVELOPMENT.

In order to keep pace with the prospecting work, the company has organized a new mine engineering office at Sinchungtze to carry on the development work. An incline was started on May 4th and a temporary power house equipped with a gasoline engine and air compressor was erected. On July 1st, a seam of coal 4.4 meters thick belonging to the B group was cut at an inclined distance of 109 m. According to the preliminary estimate, this seam was anticipated at an inclined distance of 110 m and its thickness was provisionally placed at 4.5 m. This close check between prospecting data and actual conditions as revealed by mining is gratifying. Up to now two inclines have been driven and three seams in the B group are now being developed and mined. The daily production is presently about 600 tons of coal.

OTHER MINERAL RESOURCES IN THE BASIN.

The intensive geological exploration in the Huainan basin has led to the discovery of mineral resources other than coal. The most interesting of these is the phosphate rock southeast of Fungtai. This deposit occurs at the Sinian-Cambrian contact and may be divided into three horizons. The lowest bed, about one meter thick, lies immediately above the basal conglomerate of the lower Cambrian formation. This bed is a black, dense, phosphatized sandstone or conglomerate. Under the microscope, collophanite may be seen either filling the interstices of the sandstone or replacing the entire rock. Fine crystalline aggregates of dahllite are also present, either in veinlets or replacing the fossil, *Hyolithe*. Chemical analyses show a P_2O_5 content, ranging from 20 to 25 percent, and one handpicked specimen had a phosphate content as high as 29 percent. The rock is, therefore, a medium to low grade material which will need concentration before it can be used for superphosphate manufacture. A short distance above the black phosphate bed, there are two phosphatic limestones. The lower limestone is extensively silicified, and has a yellow, gray or pink color. *Hyolithe* fossils in the form of small arrow heads or tubes are common and are especially abundant in the

gray phosphatic limestone. Both collophanite and dahllite are found; the latter replaces chiefly the *Hyolithe* fossils. These limestone beds contain only about 10 percent P_2O_5.

The siderite, as mentioned above, is widely distributed. Chemical analyses show that it has an iron content of 30 to 36 percent. The iron content could be raised to more than 50 percent by roasting and expelling the carbon dioxide. In the new coal field, seven or more layers of siderite with an aggregated thickness of about two meters have been encountered in drilling, and five or six layers are known in the old fields. It is believed that these deposits may be used at some future date as a source of iron ore.

The reserves of the diaspore clay in the basin are very great. A chemical analysis of the clay has not been made, but a microscopic study indicates a rather homogeneous composition. It may be used in the future for refractory, abrasive, and filtering materials.

Other mineral resources which are likely to be discovered are dolomite, glass sand, oil shale, pure quartzite for making silica bricks, and various kinds of clay for the ceramic industry. The discovery of a Jurassic Coal Measure in the center of the basin is also a remote possibility. All that has been archived seems to mark only a beginning, and discoveries of other and perhaps more important mineral resources are to be expected in the future.

ACKNOWLEDGMENT.

In closing, the writer wishes to express his gratitude to Mr. K. Y. Yin, Assistant General Manager of the China Development Company; Messrs. W. H. Chen and K. W. Hsu, General Manager and Assistant General Manager, respectively, of the Huainan Mining and Railway Company; and Mr. T. T. Wang, Chief Administrator of the Huainan Coal Mines, for their inspiration and cooperation throughout the work; and to Messrs, S. T. Yen, geologist, and C. Yen, topographer, and other members of the Bureau for their help in the field.

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Aug. 21, 1948.

THE DISCOVERY OF NICKEL IN EGYPT.

GERTRUDE LABIB NASSIM.

ABSTRACT.

The only known occurrence of nickel in Egypt is a small deposit of garnierite exposed near the ancient peridot workings in Saint John's Island in the Red Sea. In 1940 the writer discovered the presence of nickel in the ancient "Ab Swayel" Copper Mine. X-ray data of the nickel mineral are given. The history and geologic features of the mine are described.

INTRODUCTION.

THE "Ab Swayel" Copper Mine lies at long. 33° 38′ E and lat. 22° 48′ N in the Southeastern Desert of Egypt not far from the northern boundary of the Sudan. The mine lies on Wadi Ab Swayel which derives its name from the comparative abundance of Sayal (*Acacia arabica*) trees. The district in which the mine is located is underlain by a quartzose biotite schist which in places is garnetiferous. Within this schist and following its strike are areas of quartz occupying the main portion of the district northeast of the mine, areas of ultrabasic rock southwest of the mine, and areas of marble in the extreme southwestern portion of the district which borders a large granitic intrusive of the Um Shilman plain. Northeast of the district is the Ab Swayel micropegmatitic range which follows the strike of the schistosity of the district.

The main feature of the mine is a boss of amphibolite of lenticular outline with its main axis in the direction of the general schistosity of the district, namely 128°. Its length is about 200 m and it rises gradually from the bank of Wadi Ab Swayel to a height of 17 m at its southeastern end where it terminates against quartz and schist. Its northwestern end narrows under the floor of the wadi (valley) and on the opposite side widens again into a smaller lens. The length of both lenses is about 600 m.

HISTORY.

The Ab Swayel Copper Mine was worked in ancient times; rubble huts, furnaces, broken pottery, slag, and extracted gossan are still in evidence.

The copper implements and statues which were found in the tombs of the ancient Egyptian Pharaohs show that the copper was extracted by them as far back as the Badarian Period (1),[1] *i.e.*, in Predynastic times some 6,000 years ago. The discovery of nickel in association with the copper of this mine explains the existence of small amonuts of nickel in the ancient copper implements obtained from this mine and also explains why the ancient copper implements were harder than our present day copper objects. The following table shows the percentages of nickel in some ancient Egyptian implements

[1] Numbers in parentheses refer to bibliography at end of paper.

some of which are more than 5,000 years old and are now in the Egyptian Museum at Cairo.

The low percentage of nickel in the metallic copper of the ancients is due to the fact that the melting point of copper is much lower than that of nickel and the ancient metallurgical methods did not attain the requisite high temperatures; the result was that the main portion of the nickel in the ore remained trapped in the slag as small beads of metal. The analysis of the beads separated from ten kilograms of ancient slag gave the following results: copper, 61.20%; nickel, 14.98%; iron, 22.00%; insoluble, 1.80%; total, 99.98. This high percentage of nickel in the trapped beads explains the low content of nickel in the ancient Egyptian implements.

TABLE I.

PERCENTAGES OF NICKEL IN SOME ANCIENT EGYPTIAN IMPLEMENTS.

Object	Age	% Nickel	Analysed by	Reference
Axe	Middle Predynastic	1.3	Sir H. C. Carpenter	(2)
Axe	1st Dynasty	0.4	Prof. J. Sebelien	(3)
Adze	1st Dynasty	0.43	?	(4)
Sheet of metal of statue of Pepy 1st	4th Dynasty	1.06	Prof. G. H. Desch	(5)
Strip of copper	12th Dynasty	0.1	C. O. Bannister and H. Garland	(6)
Knife	18th Dynasty	0.3	W. B. Pollard	(7)
Winged adze	19th Dynasty	0.6	J. Sebelien	(8)

NICKEL IN THE AB SWAYEL COPPER MINE.

Since the deterioration of the ancient Egyptian civilization it can be safely assumed that this mine has not been exploited. In 1902 it was prospected for copper by the "Nile Valley Co." which company abandoned it along with its more important gold mines in 1904. This company, however, never suspected the presence of nickel in the ores (9). In 1937 Dr. W. F. Hume, Geologist of the Egyptian Government, described this mine in his book, The Geology of Egypt, as being a copper mine only (10), and, when citing the occurrence of nickel in Egypt, mentions only the small occurrence in Saint John's Island in the Red Sea (11).

In 1940 the writer visited this mine and discovered the presence of nickel in its ore and ancient slags. This is the first and only known occurrence of nickel in the Egyptian deserts.

PETROLOGY AND MINERALOGY.

The mine consists of a lenticular ultrabasic amphibolite intruded between walls of quartz-biotite-garnetiferous schist and dips 82° NE, the strike being

128° (Fig. 1). This lenticular amphibolite is divided into two parts, a barren amphibolite and an ore-bearing amphibolite.

The Country Rock Schist.—This is a garnetiferous quartz-biotite schist composed of quartz, biotite and decomposed feldspar. The quartz crystals are crushed, and show undulose extinction and the brown biotite flakes are arranged parallel to the schistosity and show partial conversion to pale green chlorite. Garnet and iron ores are accessory constituents.

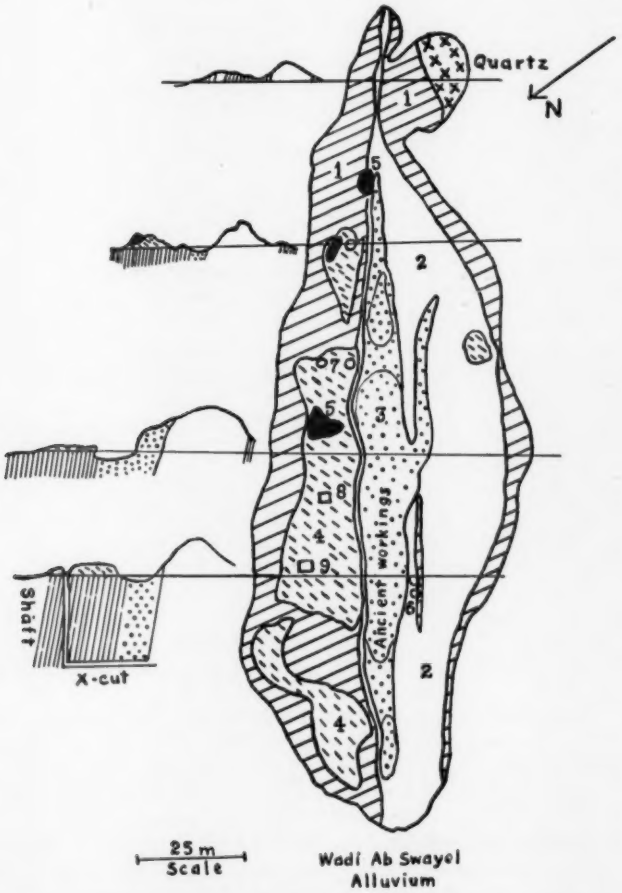

FIG. 1. Plan of Ab Swayel Mine. 1. Schist; 2. Barren amphibolite; 3. Ore zone —mineralized amphibolite; 4. Ancient dumps of rejected ore; 5. Ancient slag dumps; 6. Ore pipes; 7. Ancient furnaces; 8. Ancient room; 9. Modern shaft.

The Barren Amphibolite.—This rock is adjacent to the foot wall and is composed almost entirely of coarse grains of amphibole. It contains a little carbonate and oxides of copper and nickel though not in percentages high enough to make it of economic consideration. Two varieties of amphibole can be distinguished, not so much by their color but rather by their extinction angles,—anthophyllite and tremolite. The anthophyllite occurs in elongated almost colorless crystals and its high double refraction is shown by its bright polarization colors at the top of the first order. The anthophyllite is characteristically a stress mineral and probably developed by metamorphism from a pyroxene. Very fine grains of chromite occur as an accessory mineral in the amphibolite. Decussate structure imparts to the rock its remarkable toughness.

TABLE II.

ANALYSES OF ORE FROM THE X-CUT.

% Copper	% Nickel	Distance from contact
4.43	1.62	0 meters
3.20	1.82	1 meter
3.98	1.62	2 meters
3.98	2.03	3 meters
2.08	2.13	4 meters
3.16	2.79	5 meters
3.20	2.34	6 meters
2.92	1.72	7 meters

Average copper content is 3.37%; average nickel content is 2.01%.
A complete analysis of the sulphidic ore is as follows:

	%		%
silica	32.92	alumina	4.59
copper	3.10	selenium	nil
lead	nil	chromium	0.12
arsenic	nil	manganese	0.16
tin	nil	iron	13.14
antimony	nil	nickel	2.00
sulphur	13.50	cobalt	0.18
magnesia	17.14	combined water and oxygen	
lime	0.98	constitute the remainder	

The Ore Body.—The mineralized amphibolite is adjacent to the hanging wall and is between 9 and 11 m wide and about 200 m long. Centrally, it splits into two branches; the southern one passes into the barren amphibolite and the northern one follows the main strike and thins out into the country schist. The ore was removed by the ancient miners down to water level as is revealed by the shaft, which was sunk vertically 25 m in the hanging wall schist down to water level where a x-cut extends through 11 m of schist, 1 m of barren amphibolite, and 9 m of ore. The roof of the x-cut holed into débris of ancient filling above it. The débris is composed mainly of rejected material from the oxidized zone with bits of schist and broken pottery. The dexterity of the ancient miners is shown by their ability to continue so deep without the help of explosives and to hold the hanging wall without apparent support. It seems, however, that the mined portions were filled with waste to support the hanging wall.

In addition to the two ore-bearing branches there are also pipe-like vertical shoots. In several instances the ore-bearing amphibolite encloses masses of barren amphibolite and the ancients have undercut one of these masses in following the ore. The fillings of the pipes were also removed by the ancients. A layer of country schist about two meters thick that separates the barren and mineralized amphibolites is much crushed and is impregnated by nickel and copper oxidized minerals.

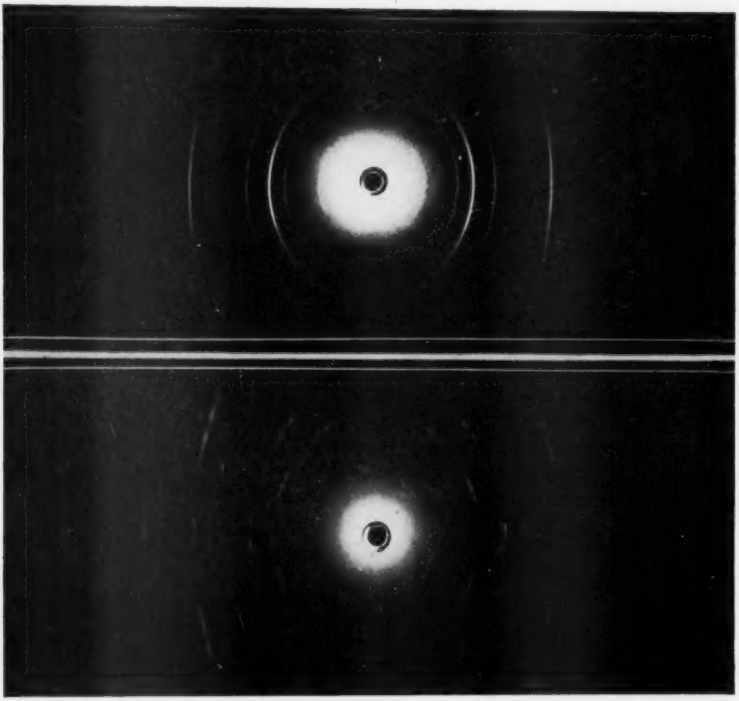

FIG. 2. (Upper) X-ray photograph of powdered Egyptian violarite. Filtered cobalt radiation, camera diameter 6 cm.

FIG. 3. (Lower) X-ray rotation photograph of crystal fragment of Egyptian violarite taken with filtered cobalt radiation 1.787 Å in a cylindrical camera diameter 6 cm.

The barren amphibolite and the ore, disclosed in the x-cut, although almost indentical mineralogically, can be distinguished by the fact that the barren amphibolite is of coarser texture and contains fewer metallic minerals than the ore. Analyses of the sulphidic ore taken from the x-cut are given in Table II.

The ore also contains small amounts of gold, silver, and platinum as follows: gold, 0.052 ounce per ton; silver, 1.5 ounce per ton, and platinum, 0.03 ounce per ton.

In the oxidized part of the ore body the copper occurs mainly as malachite, azurite and cuprite and rarely as chrysocolla; the iron is mainly in the form of hematite and rarely as limonite; and the nickel is almost absent in the gossan

TABLE III.

Dr. F. A. Bannister's data for Egyptian violarite					de Jong and Willem's data for linnaeite from Westphalia		
2r cm	d Å		I	Indices	d Å		I
	Observed	Calculated			Observed	Calculated	
1.98	5.48	5.6	w	111	—	5.4	—
3.28	3.33	3.35	m	220	3.26	3.31	3
3.85	2.85	2.86	vs	311	2.80	2.82	8
4.04	2.72	2.73	vw	222	—	2.70	—
4.68	2.365	2.37	s	400	2.34	2.34	7
—	—	2.17	—	331	—	2.15	—
5.80	1.935	1.933	w	422	1.915	1.911	3
6.20	1.819	1.823	ms	333, 511	1.802	1.801	9*
6.80	1.673	1.674	vs	440	1.656	1.655	10
7.15	1.601	1.601	vvw	531	—	1.582	—
7.72	1.499	1.497	vw	620	1.480	1.480	2*
8.06	1.443	1.444	w	533	1.431	1.428	4
—	—	1.428	—	622	—	1.411	—
8.61	1.369	1.367	w	444	1.351	1.351	5*
8.95	1.324	1.326	vw	551, 711	1.321	1.311	2
9.45	1.267	1.266	vw	642	1.256	1.251	4
9.81	1.230	1.232	mw	553, 731	1.225	1.218	6
10.35	1.182	1.184	mw	800	1.177	1.170	5
—	—	1.157	—	·733	—	1.144	—
11.2	1.116	1.116	vvw	660, 822	1.111	1.104	3
11.52	1.095	1.093	w	555, 751	1.090	1.081	9
—	—		—	662	—	1.074	—
12.11	1.059	1.059	m	840	1.055	1.047	10
—	—	1.040	—	753, 911	—	1.028	
—	—	1.033	—	842	—	1.021	
—	—	1.009	—	—	—	0.998	
13.5	0.993	0.993	mw	931	—	0.981	
14.25	0.966	0.966	s	844	—	0.955	

* Include strong reflections 440, 444, and 553 not removed by filtering the iron radiation used by de Jong and Willems to investigate linnaeite.

Violarite spinel-type a 9.47 Å.

Linnaeite spinel-type a 9.36 Å (13).

as will be explained later. In the sulphidic zone the copper is present as chalcopyrite, the iron as pyrrhotite, rarely as pyrite and marcasite, and the nickel, as violarite. Whether the nickel is in the form of pentlandite lower down remains to be seen. These sulphides are mainly finely disseminated throughout the amphibolite host rock. In thin section they are seen to occur in between the crystals of amphibole. Even when an amphibole crystal is completely surrounded by sulphide it maintains its crystalline form.

Secondary chalcocite and covellite are present, and stringers of chalcopyrite cut across earlier minerals. Secondary marcasite breaks across crystals and extends along cracks and cleavages in the amphiboles.

X-ray Examination of the Nickel Mineral.—The nickel present in the ore was found to be in the form of a nickel iron sulphide. The writer is indebted to Dr. F. A. Bannister, Deputy Keeper of Minerals of the British Museum, for the X-ray examination of this nickel iron sulphide. Table III gives the X-ray data from the X-ray photograph (Fig. 2) of powdered Egyptian violarite as obtained by Dr. F. A. Bannister and is compared with de Jong's and Willem's data for linnaeite from Littfeld, Westphalia, which possesses a similar crystal structure and therefore yields a similar powder photograph.

The unit cell dimension for violarite from Egypt as obtained by Dr. F. A. Bannister is 9.47 Å, close to values obtained by Dr. Bannister for violarite from Vermillion Mine, Sudbury, Ontario.

Oxidation of Sulphide Ore.—The ore of the sulphide zone when left in the open for a few months was found to disintegrate into a light green powder which when leached gave soluble sulphates of copper, nickel, and iron.

This property, together with the fact that the nickel sulphate so formed does not oxidize and hydrolyze like ferrous sulphate to form the oxide, explains why iron and nickel in sulphidic ores will separate by weathering, much of the iron remaining behind in the gossan while the nickel is carried away in solution. For instance, on exposing the ore to weathering and water it was found that after a time 90 percent of the nickel could be extracted as a soluble sulphate by water, while the iron sulphate was deposited as a hydroxide by hydrolysis.

COMPARISON WITH OTHER EGYPTIAN MINES.

Copper exists in small quantities in a number of localities in the Eastern Desert of Egypt as well as in Sinai. In the Eastern Desert, minor occurrences have been reported in Wadi Araba, near Bagal Darra (14), and at Gabal Atowi (15). In Sinai, copper is found in the form of malachite near the plain of Senned (16) and in a schist in Wadi Samra. Besides these minor occurrences which are of no economic importance, two main copper workings are known both of which have been worked by the ancient Egyptians. The largest, judging by the slag dump left by the ancient smelters, is near Bir Nasb in Western Sinai and the second is Um Semiuki Mine in the Eastern Desert.

Bir Nasb Slag.—Until now no copper deposit of any magnitude has been discovered anywhere within reasonable distance of the ancient slag dump near this well (Bir = well). Ancient workings, however, can be seen in the manganese deposits of the district, which are known to contain small nodules of copper carbonate. Copper must have had great value in those days for such small nodules to be collected in quantities so great as to leave such an enormous slag dump. This slag was described by Bauerman (17). It was estimated by Prof. Petrie (18) at 100,000 tons and by T. A. Rickard (19) at 50,000 tons. The writer has visited the vicinity and the ancient workings; the analysis of

both the slag and the copper beads enclosed therein revealed them to be entirely free from nickel.

Um Semiuki Copper Mine.—This mine is described by Dr. Hume (20) as consisting of a mineralized layer containing chalcopyrite and zinc blende with a hanging wall of felsite and a foot wall of diabasic conglomerate.

Saint John's Island in the Red Sea.—A small occurrence of nickel in the form of garnerite in an ultrabasic rock is found in the vicinity of ancient peridot workings.

ACKNOWLEDGMENT.

The writer gratefully acknowledges the help she received from Dr. F. A. Bannister, Deputy Keeper of Minerals of the British Museum, by making the X-ray analysis of the nickel mineral of the Ab Swayel Mine and identifying it as violarite.

ABBASSIA, CAIRO, EGYPT,
Oct. 1, 1948.

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21. Phemister, T. C., A note on the Lancaster Gap Mine, Pennsylvania: Jour. Geology, vol. 32, No. 6, pp. 498–510, 1924.

DISCUSSION AND COMMUNICATIONS

TRANSPORT AND DEPOSITION OF THE NON-SULPHIDE VEIN MINERALS. III. PHASE RELATIONS AT THE PEGMATITIC STAGE.

Sir: I refer to the paper of the above title that appeared in the November number of ECONOMIC GEOLOGY, pages 535–546, 1948.

The results of Goranson on the system water-albite have been misinterpreted as indicating the formation of two immiscible liquid layers. This misconception probably has come from his use of the term "fluid phase" to indicate a gas under special conditions. For example, he wrote, "There are then two coexistent fluid phases—one predominating in silicates, the other in water. . . . The pressure necessary to hold this amount of water in solution at 700° will be equivalent to the hydrostatic head at this depth and thus further crystallization would be accompanied by an ebullition of water with formation of two coexistent fluid phases." [1] In another place he wrote, "In either case a separation into two fluid phases will take place. . . . This limited miscibility of water. . . ." [2]

It is clear, however, that by two fluid phases he meant a gas and a liquid. For example, in the first of the series of papers dealing with this system he wrote, "The runs were from 2–4 hours duration, which was found to be sufficient time for attaining equilibrium between the gas-liquid phases." [3] In the last of this series of papers he wrote, "In these investigations the homogeneous parts are: (1) a vapor phase which is essentially water, (2) a liquid phase which is a saturated solution of water in a silicate melt, and (3) solid phase or phases consisting of one or more silicates." [4]

The use of the term "fluid phase" probably is the cause of some confusion. We deal with the three states of matter: solid (crystalline), liquid, and gas. A liquid is a non-crystalline phase which does not tend indefinitely to expand and fill the available space; a gas is a non-crystalline phase which does fill all available space. The existence of a pure liquid ordinarily is terminated by a critical point, at which liquid and gas become identical in properties, and above the critical temperature a liquid can no longer exist. If the pressure

[1] Goranson, Roy W., Some notes on the melting of granite: Am. Jour. Sci., 5th ser., vol. 23, pp. 227–236, March 1932.

[2] Goranson, Roy W., Silicate-water systems; "osmotic-pressure" phenomena and their bearing in some problems of igneous activity: Am. Geophys. Union Trans. 18th Ann. Mtg., Pt. 1, pp. 246–247, Nat. Research Council, July 1937.

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[4] Goranson, Roy W., Silicate-water systems: Phase equilibria in the $NaAlSi_3O_8$–H_2O and $KAlSi_3O_8$–H_2O systems at high temperatures and pressures: Am. Jour. Sci., 5th ser., vol. 35–A, pp. 71–91, 1938.

on water is lowered from above the critical pressure, and at a temperature above the critical temperature, it will expand indefinitely; it is a gas no matter how much it is compressed. If the temperature is below the critical, on lowering the pressure to the vapor pressure of water at that temperature two phases will separate, a gas or vapor, and a liquid.

The term "vapor" is used to indicate a gas at a temperature at which it can be compressed to a liquid; usually, but not necessarily, it is considered as being coexistent with a liquid. This definition is clear when dealing with a pure substance, but in binary systems it becomes either indeterminate or arbitrary. Consider a solubility curve in such a system as H_2O—K_2SiO_3 or H_2O—KCl. The solubility curve is continuous; the 3-phase equilibrium gas + solution + solid is continuous and the critical temperature of water is no special point on it, any more than is the boiling point of water. The gaseous phase, then, which is essentially water, can be compressed to liquid at any temperature along the curve. If it is a vapor, the definition of vapor must include specification of the system, and the definition of vapor becomes almost meaningless. If the definition is restricted to pure substances, the equilibrium is vapor + liquid + solid below the critical temperature of water, gas + liquid + solid above this point, a purely arbitrary restriction. A vapor is a special case of a gas; it is better to consider the general case and speak of the 3-phase equilibrium gas + liquid + solid, and not be too pedantic about the definition of vapor.

By the degree of filling is usually meant the ratio of the amount of water to the free volume of the containing vessel. When the non-volatile ingredients remain solid, that is, when no aquo-igneous fusion takes place, the degree of filling uniquely determines the pressure at a given temperature. When the degree of filling is less than the critical volume, the water is all gaseous below the critical temperature. When the degree of filling is greater than the critical volume, the vessel becomes filled with liquid below the critical temperature, but above the critical temperature, it is gaseous by definition. These simple relations depend on the properties of pure water, and when in a more complex system a liquid is formed they are no longer true. The pressure is the vapor pressure of the liquid, and may be far less than that calculated from the degree of filling. The more water present, the more is in the liquid; the rest will be a gas, a gaseous solution. If the system is truly binary, coexistence of gas + liquid + solid at a given temperature will be possible only at one pressure, that is, one degree of filling. With less water, there will be gas + solid; with more water, gas + liquid. With more complex systems the coexistence of gas + liquid + solid has more degrees of freedom, and coexistence of these three phases will be possible under a range of pressures.

In a binary system showing critical end-points, there is a region between the two end-points in which a liquid cannot exist, although both above and below this region gas + liquid + solid is possible. Van der Waals used the term "fluid" to indicate the gas in this region, primarily to emphasize that this gas was as much a solution as the liquids above and below the critical end-points. The phase is a gas; that a gas can contain solid material in solution is now well known; and to continue to use the term "fluid" in this sense

is conducive to confusion. It appears better to avoid "vapor" and "fluid" in all discussions of systems containing volatile components and to use the more general term "gas."

The assumption of the formation of two immiscible liquids in systems such as water-albite or water-silica at first seems tempting. There is a first critical end-point in such systems, and the solubility in water is so small that it is at the critical point of water. Where can be the second critical end-point? Since at the end-point the compositions of gas and liquid are the same, either the gas must contain only a small amount of dissolved silica, in which case the critical temperature would not be expected to be very high, or it must

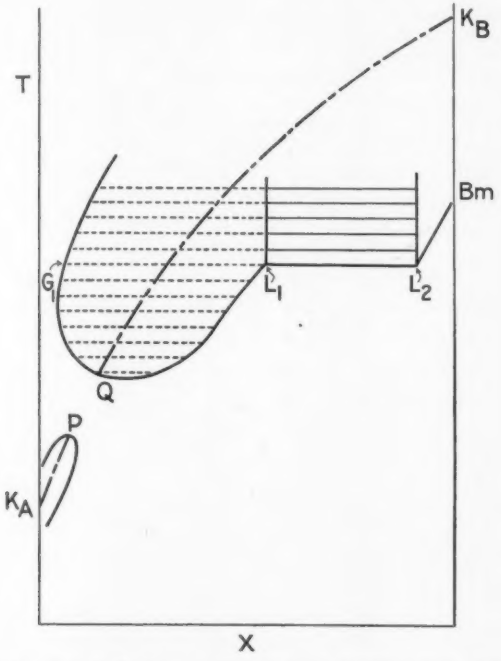

FIG. 1. Schematic T–X diagram illustrating a simple case of formation of two liquid layers in a system showing critical end-points (G = L) + S. K_A and K_B are the critical points of the components, which are joined by the critical curve K_AK_B, interrupted at the critical end-points P and Q. From the quadruple point $G_1 + L_1 + L_2 + B$ proceed (1) the univariant equilibrium $G + L_2 + B$ (curve L_2B_m); the composition of the gas is not shown. (2), the univariant equilibrium $G + L_1 + L_2$; the coexisting liquids are joined by full lines, the gas by dotted lines. (3) the equilibrium $G + L_1 + B$, the curve G_1 Q L_1; the coexisting gaseous and liquid phases are connected by dotted lines, and at Q, (G = L_1). The fourth univariant equilibrium, $L_1 + L_2 + B$, is not shown. The term, "fluid," has been used to indicate the gas between P and Q.

contain a large amount of silica. It is tempting to assume that after an initial lowering of melting point along the curve B_mL_2 (Fig. 1) a second liquid, rich in water, is formed, and that it is the liquid L_1 which reaches the critical end-point Q. But this does not help. We still must have a critical end-point Q, at which G = L, and we have introduced the additional complication of a two-liquid region extending above the invariant point $G + L_1 + L_2 + B$, for which there is no justification. As far as I can see, there is no experimental evidence which makes probable the formation of two immiscible liquids in water-silicate systems.

GEORGE W. MOREY

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTION OF WASHINGTON,
WASHINGTON, D. C.,
December 2, 1948.

REVIEWS

Structure of Typical American Oil Fields, Vol. III. Edited by J. V. HOWELL. Pp. 516; figs. 219. Amer. Assoc. Petrol. Geol., Tulsa, Oklahoma, 1948. Price, $4.50.

This volume is a worthy successor to its two excellent predecessors and is the newest book of the structure series gotten out by the Association.

Twenty-four papers describe oil fields in 12 states and Canada. There has been chosen for this volume those fields characterized by distinctive or peculiar features of stratigraphy, structure, and accumulation. It is of course a symposium contributed to by 30 authors. The individual subjects covered are: Gilbertown Field, Choctaw County, Alabama, by A. M. Current; Fouke Oil and Gas Field, Miller County, Arkansas, by C. B. Schwartz; Geology of Aliso Canyon Field, Los Angeles County, California, by Claude E. Leach; Cymric Oil Field, Kern County, California, by J. H. McMasters; Geology of Edison Field, Kern County, California, by J. H. Beach; Norman Wells Oil Field, Northwest Territories, Canada, by J. S. Stewart; Gramp's Field, Archuleta County, Colorado, by W. A. Waldschmidt; Rangely Oil Field, Rio Blanco County, Colorado, by W. Y. Pickering and C. L. Dorn; Marine Pool, Madison County, Illinois Silurian Reef Producer, by Heinz A. Lowenstam; Omaha Pool and Mica-Peridotite Intrusives, Gallatin County, Illinois, by R. M. English and R. M. Grogan; Augusta Field, Butler County, Kansas, by George F. Berry, Jr. and Paul A. Harper; Geneseo Uplift, Rice, Ellsworth, and McPherson Counties, Kansas, by Stuart K. Clark, C. L. Arnett and James S. Royds; Kraft-Prusa Oil Field, Barton County, Kansas, by Robert F. Walters and Arthur S. Price; Creole Field, Gulf of Mexico, Coast of Louisiana, by Theron Wasson; Deep River Oil Field, Arenac County, Michigan, by Kenneth K. Landes; Deerfield Oil Field, Monroe County, Michigan, by George D. Lindberg; Arcadia-Coon Creek Pool, Oklahoma and Logan Counties, Oklahoma, by George E. Carver, Jr.; Cumberland Oil Field, Bryan and Marshall Counties, Oklahoma, by Ira H. Cram; Geology of West Edmond Oil Field, Oklahoma, Logan, Canadian, and Kingfisher Counties, Oklahoma, by Robert Malcolm Swesnik; Apco Field, Pecos County, Texas, by Samuel P. Ellison, Jr.; Quitman Oil Field, Wood County, Texas, by E. R. Scott; Talco Oil Field, Franklin and Titus Counties, Texas, by E. A. Wendlandt and T. H. Shelby, Jr.; Rose Hill Oil Field, Lee County, Virginia, by Ralph L. Miller; Steamboat Butte Oil Field, Freemont County, Wyoming, by H. E. Barton.

Of the fields included 18 have not been described before. This volume, in distinction to its predecessors, has had the opportunity to include all the newer methods of research such as the various types of logging, areal photographs, deeper drilling and reservoir studies. As will be seen from the titles, a wide variety of types of accumulation, and condition are covered.

The Editor, the Association, and the authors deserve thanks for another excellent work.

Mineralogical and Structural Evolution of the Metamorphic Rocks. By F. J. TURNER. Pp. 342; figs. 85. Geol. Soc. America Mem. 30, 1948. Price, $3.00.

This memoir brings together current views on the origin of metamorphic rocks and is meant for advanced students and research workers who are familiar with

metamorphic petrography. It deals with much of the author's own work and covers the literature of the last two decades.

The best idea of the contents may be gained from the chapter headings, which are: 1, Scope of Metamorphism; 2, Chemical Adjustment of Solid Rocks to Temperature, Pressure, and Shearing Stress; 3, Metamorphic Zones; 4, The Phase Rule and Metamorphic Facies; 5, Characteristics of the Principal Metamorphic Facies—I; 6, Characteristics of the Principal Metamorphic Facies—II; 7, Metasomatism in Metamorphism; 8, Metamorphic Differentiation; 9, Some General Characteristics of the Fabric of Metamorphic Rocks; 10, Fabric of Deformed Rocks—I, Development of Slip Surfaces During Deformation of Rocks; 11, Fabric of Deformed Rocks—II, The Basis of Petrofabric Analysis; 12, Fabric of Deformed Rocks—III, Some Typical Patterns of Preferred Orientation; 13, Experimentally Established Data Relating to Plastic Deformation of Crystalline Materials and Evolution of Tectonite Fabrics; 14, Mechanism of Development of Tectonite Fabrics in Metamorphic Rocks; 15, Some Special Problems of Regional Metamorphism.

Of particular interest to readers of this Journal is chapter 7 on Metasomatism in Metamorphism, which deals with the laws of metasomatism, classification of the main types, metasomatism with introduction of Si, Sn, B, Li, F, Cl, or S, and hydrothermal metasomatism of peridotites. Also of interest are chapter 14 on the mechanism of development of tectonic textures such as orientations of quartz, mica, calcite, and schistosity, and the last chapter on special problems which takes up the causes of metamorphism, sources of heat, deformation, retrogressive metamorphism, the nature and origin of migmatites, and granitic bodies. An extensive bibliography follows.

The book commands respect and will unquestionably become a standard text book for advanced petrology students.

BOOKS RECEIVED.

ALAN T. BRODERICK.

U. S. Geological Survey—Washington, D. C., 1948.

Bull. 954–D. Optical Calcite Deposits of the Republic of Mexico. CARL FRIES, JR. Pp. 66; pls. 10; figs. 8. *Usable material occurs as crystal linings of small cavities in veins, breccias, in Tertiary or later volcanics. In addition to deposit descriptions, report covers Specifications; Common Defects; Consumption, Markets and Prices; Methods of Mining; Cleaving, Selecting. Valuable reference.*

Bull. 959–C. Geophysical Abstracts 134—July–September 1948. V. L. SKITSKY AND S. T. VESSELOWSKY. Pp. 86.

Water-Supply Paper 995. Index to River Surveys Made by the United States Geological Survey and Other Agencies. BENJAMIN E. JONES AND RANDOLPH O. HELLAND. Pp. 145.

U. S. Bureau of Mines—October 1948.

R. I. 4355. Investigation of the Sauk Mountain Limestone Deposits, Skagit County, Wash. CONSTANTINE C. POPOFF. Pp. 14; tbls. 2; figs. 4.

R. I. 4357. Investigation of the Sutherland Copper Prospect, Floyd County, Va. WESLEY A. GROSH. Pp. 2; figs. 3. *Negative results of 913 feet of drilling a pyrrhotite-chalcopyrite zone in mica schist.*

R. I. 4359. Investigation of the Minah Lead-Silver Mine, Jefferson County, Mont. S. H. LORAIN AND R. J. HUNDHAUSEN. Pp. 9; figs. 5. *Negative results of 5,600 feet of trenching, 1,095 feet of drilling near fissure filling in andesite roof pendant of the Boulder batholith.*

R. I. 4361. Investigation of the Rainy Creek Mercury Prospect, Bethel District, Kuskokwim Region, Southwestern Alaska. F. A. RUTLEDGE. Pp. 7; figs. 5. *2,940 feet of trenching show disseminated cinnabar, realgar, in and between two shear zones in Permian (?) sediments. Best section averages 8.2 lbs. Hg over 6.3 feet. Highest assay, 45.8 pounds per ton; average width 3 inches.*

R. I. 4364. Diamond Drilling at Union Copper Mine, Cabarrus and Rowan Counties, N. C. T. J. BALLARD AND AUSTIN B. CLAYTON. Pp. 9; figs. 8; tbls. 2. *2,500 feet of drilling along a mineralized shear zone between schist and granite indicate the presence of zinc mineralization north of the old copper stopes.*

Shasta and California Iron-Ore Deposits, Shasta County, California. CARL A. LAMEY. Pp. 27; fig. 1; pls. 3. California Division of Mines, Bull. No. 129, Part K, San Francisco, October 1946. *Estimate 3,893,000 tons 41.3% Fe; 13.2% SiO_2; .014% P. Magnetite in lenses formed by contact-metasomatic replacement and fracture filling near a late Jurassic or early Cretaceous quartz diorite.*

Illinois Geological Survey—Urbana, 1947–1948.

Bull. 72. Briquetting Illinois Coals without Binder. R. J. PIERSOL. Pp. 198; tbls. 83; figs. 109. *Briquets made without binder have lower smoke index than original coal. Partial prevolatilization prior to briquetting reduces low-temperature fraction so that briquets have a lower smoke-index than that of Pocahontas coal.*

Rep. Inv. 124. Geological Structure of the Zinc-Lead District of Northwestern Illinois. H. B. WILLMAN AND R. R. REYNOLDS. Pp. 15; pls. 7. *Structure contour maps of top of Oilrock formation based on all available drill-hole and mine data.*

Rept. Inv. 128. Clay and Shale Resources of Extreme Southern Illinois. J. E. LAMAR. Pp. 107; figs. 8.

Shipping Coal Mines in Illinois. GILBERT H. CADY. *Geographic map, 1:500,000 showing type of mine, production, freight rates.*

The Stratigraphy and Structural Development of the Salina Basin of Kansas. WALLACE LEE, CONSTANCE LEATHEROCK AND THEODORE BOTINELLY. Pp. 155; pls. 14; figs. 11; tbls. 18. Kansas Geological Survey Bull. 74, Univ. of Kansas Pub., Lawrence, Nov. 1948.

Geological Survey and Water Resources. EDWARD L. CLARK. Pp. 31. Missouri Geological Survey 65th Biennial Report, Rolla, 1948.

Sixth Biennial Report of the Oregon State Department of Geology and Mineral Industries, July 1, 1946 to July 1, 1948. Pp. 49; figs. 6. Bull. 38, Portland, 1948.

The Geology of the County South of Ermelo—An Explanation of Sheet No. 64. H. N. VISSER, L. J. KRIGE AND F. C. TRUTER. Pp. 110; pls. 10; colored geol. map 1:125,000; coal outcrop map 1:75,000. South Africa Department of Mines, Pretoria, 1947. *About 4 billion short tons of coal estimated in this 2,300 square mile area of Karroo and earlier rocks.*

Annales du Service des Mines, Comité Spécial du Katanga, Tomes XII–XIII, 1947–1948. P. GROSEMANS, A. JAMOTTE AND L. CAHEN. Pp. 188; numerous plates and figures. Bruxelles, 1948. *Six papers on Katanga geology including one which attributes Katanga's banded ironstones to metamorphism (including quartz injection) of amphibolites of both sedimentary and igneous origin.*

Le Congo Physique, Complément 1948 à la 3e Edition. MAURICE ROBERT. Pp. 82; figs. 6. Liège, 1948. *Supplement to the 3rd edition.*

Geological Map of British Columbia, No. 932–A. 1948. *1" = 20 miles, colored, compiled from Geological Survey and Dept. Mines maps.*

Ontario Department of Mines—Toronto, 1948.

56th Annual Report, Vol. LVI, Part I, 1947. Pp. 102; tbls. 7.

Map 1947–3. Township of Michaud. *32" × 32", 1:12,000, colored.*

Instituto de Fisiografía y Geología de Argentina—Rosario, 1948.

Crónica Bibliográfica. ALFREDO CASTELLANOS AND PIERINA PASOTTI. Pp. 157. *Abstracts of Argentine geologic and related publications.*

El Puelchense de Buenos Aires y su Fauna (Plioceno Medio). CARLOS RUSCONI. Pp. 99; figs. 31. *A water-bearing sand deposit of Buenos Aires and its fauna.*

18th International Geological Congress—London, 1948.

The Geology of Eastern Ireland. D. W. BISHOPP ET AL. Pp. 35; figs. 8.

Guides to Excursions. *These guidebooks contain from 10 to 70 pages and are illustrated by small-scale maps, tables and figures.*

A.1, Economic Geology of England and Wales. A.2, North-West of England. A.3, "William Smith" Excursion (Environs of Bath). A.4, Devon and Cornwall (Mineralogical). A.5 and C.5, Devon and Cornwall (General). A.6, Oxford District. A.7, West Midlands. A.8, Dorset Coast. A.9, Pennines. A.10, South Wales. A.11, London to Wales (Geomorphology). A.12, Mull and Ardnamurchan. A.13, Isle of Skye. A.14, North-West Highlands: Assynt and Durness. A.15, Arran and South-West Scotland. A.16, South-West Highlands. A.17 and C.17, East Anglia. A.18, Hydrogeology of England and Wales. A.19, Scotland (General Tour). C.1, England and Wales (General Tour). C.2, North-East Yorkshire. C.3, Bristol District. C.4, East Midlands. C.6, North Wales and Shropshire. C.7, Central and South-West Wales. C.8, Isle of Wight. C.9, North-East Coast. C.10, East Ireland. C.11, Ben Nevis Glen Coe, Ballachulish Area. C.12, East Highlands. C.13, Edinburgh and St. Andrews. C.14, Skye and Morar. C.15, Glasgow District. C.16, Vertebrate Palaeontology. C.18, Jersey.

Direcção Geral de Minas e Serviços Geológicos de Portugal—Porto, 1947–1948.

Rochas e Minérios da Ragião Bragança-Vinhais. J. M. COTELO NEIVA. Pp. 251; pls. 75. *Report on geologic, petrographic, mineralogic, genetic study of the rocks of Bragança-Vinhais County, Portugal, which include chromite-bearing saxonites. Writer concludes that a small part of the chromite was early, part was contemporaneous with the silicates, most of it collected as a rest-magma which was then injected.*

Estudos, Notas e Trabalhos. Vol. III, Fasc. 3. Pp. 192; figs. 13; tbls. 13.

Vol. III, Fasc. 4. Pp. 264; figs. 7; pls. 5; tbls. 4; 5 colored maps.

SCIENTIFIC NOTES AND NEWS

CHARLES P. BERKEY, Newberry professor emeritus at Columbia, was awarded the Kemp Medal for distinguished service in geology by Columbia on October 26 at the Faculty House.

JOHN G. BARAGWANATH, of the Freeport Sulphur Co., returned last September from Paris, where he acted for five weeks as a consultant on strategic minerals for the industry division of ECA-Paris. He also visited London and The Hague.

RAY E. MORGAN resigned as chairman of the department of mining and geology at West Virginia Institute of Technology, and is now associate professor of economic geology at the School of Mines and Metallurgy, University of Missouri, Rolla.

RICHARD V. PORRITT, formerly assistant general manager, has been appointed manager at Noranda of Noranda Mines, Ltd.

R. E. STOIBER, during his sabbatical leave from Dartmouth College where he is professor of geology, is working for the U. S. Geological Survey in the copper country of northern Michigan with headquarters at Calumet.

WALTER H. VOSKUIL, mineral economist with the Illinois State Geological Survey, has been appointed professor of mineral economics and will teach part time in the department of mining and metallurgy at the University of Illinois. Dr. Voskuil will continue his work with the Survey.

W. W. "Doc" HAMMOND, who worked as a geologist for the Magnolia Petroleum Co. for over eighteen years, left his post as district geologist of their San Antonio district to accept the post of chief geologist for Fair-Woodward, San Antonio.

THOMAS E. NORTHROP has returned to the States after serving as deputy director of the Bureau of Mines in Korea.

KEITH WHITING, chief geologist of the northwest mining department of the American Smelting and Refining Co., returned from a field trip he made to the Kenya Colony, British East Africa.

FREDRICK C. KRUGER, Assistant Chief Geologist for the Cerro de Pasco Copper Corporation, is on leave of absence and will be at Northwestern University as Lecturer in Geology during winter and spring quarters of 1949.

The library of the late Dr. Gayle Scott, eminent Texas geologist well-known in both the oil industry and in scientific circles throughout the world, has been donated to Texas Christian University by Mrs. Mary Beth Scott. The complete collection will be available to outside scientists and industrial personnel as well as to TCU students and faculty members. One of the most complete libraries on Texas geology, it also includes a collection on fossil ammonites, of great economic importance in correlation of the earth's strata; a collection of 1528 reprints of world-wide geological articles, most of them autographed and out of print; numerous publications and books; all of Dr. Scott's own writings, his class and field notes which

include exhaustive background materials on the economic, historical and cretaceous phases of geology. Especially valuable are Dr. Scott's notes on his study of the geology of France, which added weight to the theory of continental drift.

ERNEST R. LILLEY has been elected vice president in charge of the Great Lakes Carbon Corporation's Oil and Gas Division and will also continue as its chief geologist with headquarters at the Corporation's New York general office.

WALTER O. SNELLING, consulting chemist and Director of Research of the Trojan Powder Company, Allentown, Pa., has been appointed to the Atomic Energy Commission's Advisory Committee on Raw Materials.

WILLIAM H. EMMONS, for 34 years Head of the Department of Geology of the University of Minnesota and past President of the Society of Economic Geologists, died on November 5, 1948.

Eight volumes of papers on soil mechanics and foundation engineering, prepared in conjunction with the Second International Conference on Soil Mechanics and Foundation Engineering held at the Hague, Netherlands, last June, are now available. The Proceedings consist of six volumes; the first five contain papers covering every phase of soil mechanics and foundation engineering, with particular emphasis on field observations, field testing and foundation, dam, highway and airfield construction. The sixth volume contains the lectures, reviews, and discussions presented at the meetings. Because of the number of papers submitted, a seventh volume is to be published if sufficient orders are received. Orders for the Proceedings should be sent to the Secretary, Second International Conference on Soil Mechanics and Foundation Engineering, Oostplantsoen 25, Delft, The Netherlands. The approximate costs are $29.30 for Vol. I to VI; $5.65 for Vol. VII. In addition a volume containing the German developments can be obtained from the Library, Graduate School of Engineering, Harvard University, Cambridge 39, Mass., at a price of $6.50.

PAUL WEAVER, president of the American Association of Petroleum Geologists, delivered three lectures before the Geological-Mineralogical Journal Club at the University of Michigan on January 13 and 14. His topics were "Frontiers of Petroleum Geology," "Formation of Marine Evaporites," and "Limestones in the Tertiary along the Gulf of Mexico."

LOUIS C. BALL has been appointed geologist of the Standard Gypsum Company, with headquarters in the Kaiser Building, Oakland, California.